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**HOW IT
WORKS**
BOOK OF

GREAT INVENTORS

& THEIR CREATIONS

This book celebrates some of history's greatest minds, whose intelligence and perseverance has helped shape the modern world. They are by no means the only great inventors in history, but within these pages you'll meet some of the most iconic figures in the history of technology. Among many others, you will encounter brilliant mathematicians Archimedes of Syracuse and Charles Babbage, celebrated scientists Michael Faraday and Alfred Nobel, and photography pioneers Nicephore Niépce and George Eastman. How It Works Book of Great Inventors & Their Creations will offer an insight into the careers of these geniuses through amazing articles, informative diagrams and handwritten notes. So, turn the page and witness the innovative spirit and insatiable drive possessed by the men and women who conceived of some of the world's most influential inventions.

HOW IT WORKS BOOK OF GREAT INVENTORS & THEIR CREATIONS

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WORKS**
bookazine series



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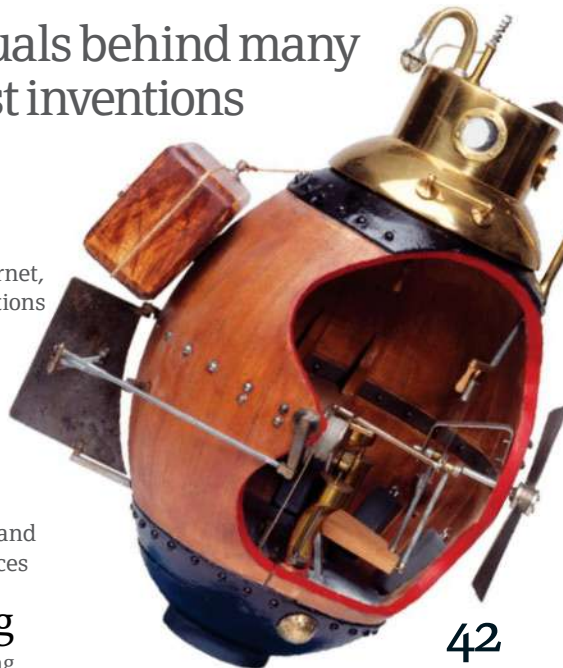
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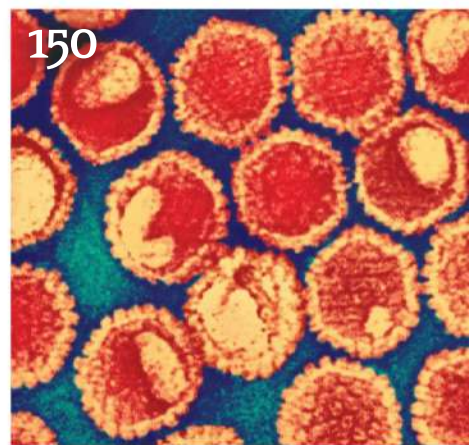
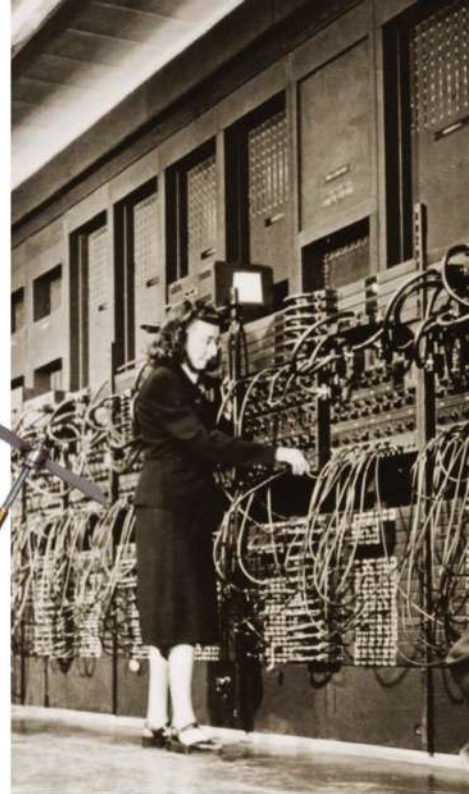
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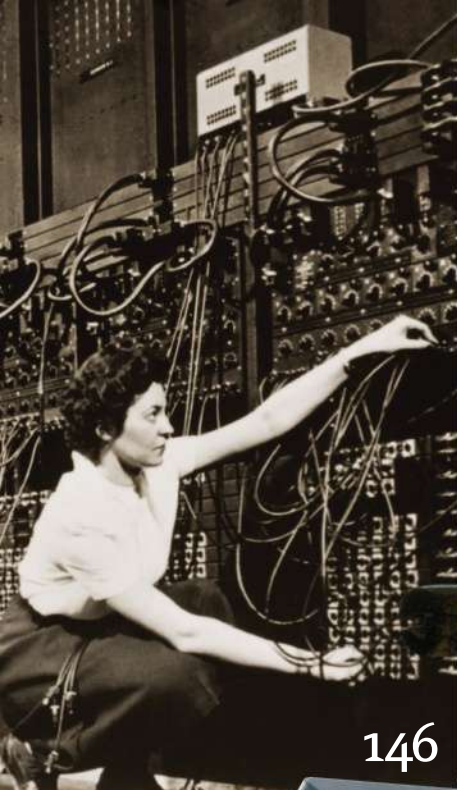
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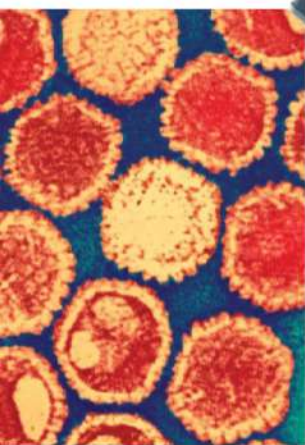
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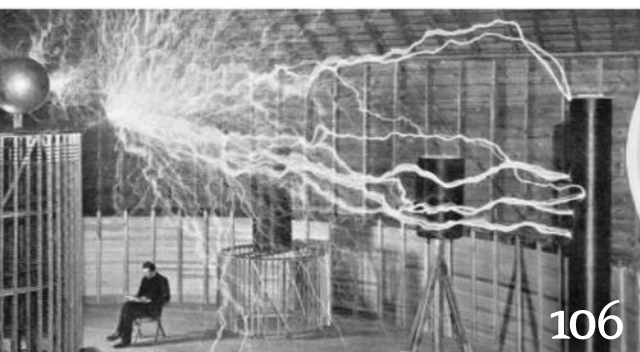




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GREAT INVENTORS AND THEIR CREATIONS

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INVENTIONS THAT CHANGED THE WORLD





Every invention and inventor has a story; a means by which the creation was conceived when others had either failed or simply didn't realise it could be done. Some have been the evolution of an earlier idea into something others had tried to attain – building the world's first powered airplane, for example. Other inventions have more humble beginnings, such as plastic, which struggled to achieve commercial success for 50 years after its invention until it suddenly sprang into the limelight and became an integral part of the modern world.

Many inventions have changed the world in entirely different ways. The Internet and telephone enabled people to communicate on a global scale instantaneously for the very first time.

Touch screens and televisions have let people receive and navigate information in whole new ways, while the Wright brothers' plane and steam engines paved the way for transportation to become easy, quick and efficient.

However, not all inventors had this long-term vision when creating their

inventions invented by accident that often have the greatest impact.

Of course, there has been many a time where an invention has been anything but accidental, and the race to file a patent or show the idea to the general public has been intense. When Alexander Bell went up against Elisha

Gray in the race to patent the first telephone, the former won out by a matter of hours.

Narrowing down every invention to a list of ten certainly was not

an easy process, and of course there will be era-defining gadgets and machines that do not appear in this collection. However, what follows are ten of the most incredible inventions that have, without a doubt, changed the world that we live in and the way that we live our lives.

“It's the inventions invented by accident that often have the greatest impact”

designs. In 1862, when Alexander Parkes unveiled the first man-made plastic, did he realise how ingrained in everyday life plastic would become by the end of the 20th century? Probably not. Did Tim Berners-Lee design the world wide web knowing that it would rule the world? This is highly unlikely. It's the

Printing Press (1450)

The printing press revolutionised the accessibility and proliferation of knowledge

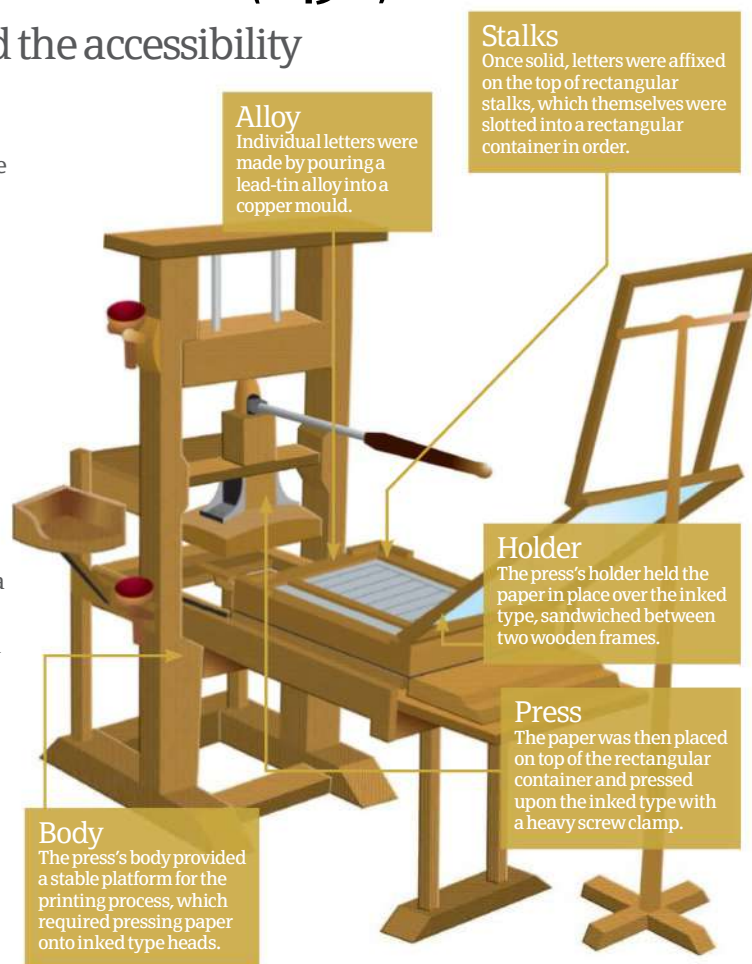
Widely considered by academics to be one of the most influential inventions of the past 1,000 years, the printing press set in motion the democratisation of knowledge and the establishment of our modern, knowledge-based economies. For the first time, valued texts could be produced in their thousands and allowed texts to be accessed widely by the majority, not just the wealthy aristocracy and intellectual elite.

The man credited with the invention of the printing press is inventor Johannes Gutenberg. Around the year 1440, Gutenberg designed a device based on screw presses that, when partnered with inked movable type heads, allowed paper to be quickly and efficiently pressed with letters. Type heads were made by pouring a lead-tin alloy into a hand mould, and then affixed to the top of movable, rectangular stalks. The stalks could then be arranged in order to create words and sentences within a rectangular container, before being fed under a screw press. The screw press clamped a paper sheet on top of the type heads, pressing their ink onto the sheet.

This was a groundbreaking invention in the 15th century. Before the Gutenberg press, texts were hand copied by monks and select few learned individuals. As such, the availability and cost of texts was immense and could only be accessed by a tiny percentage of people. Consequently, by the mid 16th century and on to the Renaissance, printing presses had exploded all over Western Europe, producing millions of mass-produced texts on a diverse array of topics. Indeed, famous English philosopher Francis Bacon said that the emergence of typographical printing had “changed the whole face and state of things throughout the world.”

Johannes Gutenberg

Johannes Gutenberg is considered the father of the Printing Revolution and the inventor of the printing press. A German blacksmith and goldsmith by trade, Gutenberg designed a complete printing system circa 1439 based on the idea of movable type. By creating type heads in a hand mould and then mounting them in the order of words, Gutenberg's machine could ink-press sheets of paper onto them far quicker than copying by hand, which was the primary manner of production at the time.



“Printing presses had exploded, producing millions of mass-produced texts on diverse topics”





The telescope's usage ranges from amateur stargazing to intergalactic analysis by NASA's Hubble Space Telescope.

Telescope⁽¹⁶⁰⁹⁾

The most important tool in astronomy, it has broadened humanity's knowledge of the universe

Invented at the start of the 17th century and named by Greek mathematician Giovanni Demisiani in 1611, the telescope elongated humanity's vision on Earth and, due to work by Galileo Galilei, its view of space. The latter has resonated to the present day with particular importance, with the telescope's usage extrapolated into a multitude of applications and disciplines, ranging from simple amateur stargazing through to intergalactic analysis by NASA's Hubble Space Telescope. Speaking on the telescope, Galileo

stated: "Alas! Your dear friend and servant Galileo has been for the last month hopelessly blind; so that this heaven, this earth, this universe, which I by my marvellous discoveries and clear demonstrations had enlarged a hundred thousand times beyond the belief of the wise men of bygone ages, henceforward for me is shrunk into such a small space as is filled by my own bodily sensations."

The credit for the basic design of modern astronomy telescopes is attributed to English polymath Sir Isaac Newton, who in 1668 invented the



world's first fully functional reflecting telescope system. Newton's reflector worked by using an arrangement of curved mirrors to gather transmitted light and return it along an optical path to a point of focus, directly visible to the scope's user through an eyeglass.



Steam Engine⁽¹⁷¹²⁾

Allowing for items to be manufactured on a large scale, the steam engine opened up incredible possibilities

The power of steam, even to this day, is harnessed worldwide. Indeed, 80 per cent of the world's electricity is generated through large-scale steam turbines, a direct evolution from the first engine produced in Egypt by Hero of Alexandria in the first century AD and the multitude of engines that powered the mills, mines and automobiles of the Industrial Revolution. If it were not for this simple yet powerful device, the evolution of further engines and our ability to generate energy could have been severely compromised.

Steam engines work by exploiting the expansion that steam demonstrates under high-pressure conditions,

harnessing a portion of the expanding fluid's heat energy to drive mechanical apparatus, such as a piston and drive wheel. In the majority of steam engines, steam is supplied via a boiler, which itself is pumped with a continuous supply of water. The boiler heats up the water, turns it into steam and then feeds it into a cylinder at high pressure. The expanding steam then pushes the cylinder's piston one way or the other – the direction is dictated by a slide valve – creating mechanical movement. While early steam engines were incredibly inefficient, requiring subsequent design revisions by engineers Thomas Newcomen, James Watt and Matthew Boulton throughout

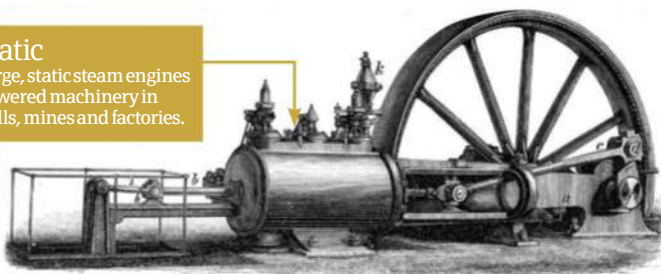
the 19th century, numerous advances led to powerful steam-powered machines – such as the steam turbine – as well as technologies that would later be included or built upon in internal combustion engines.

The rise of steam power granted a new exploitable form of energy but also ushered in the age of automation and mass-production. With steam-powered machines undertaking the role of humans – often with a higher product output – items could be manufactured on a large scale. This led to the invention of the production line, a process that was later exploited by Henry Ford among others in the proliferation of cars, weapons and appliances.

“Powering the Industrial Revolution, the steam engine enabled extensive mechanisation and automation”

Static

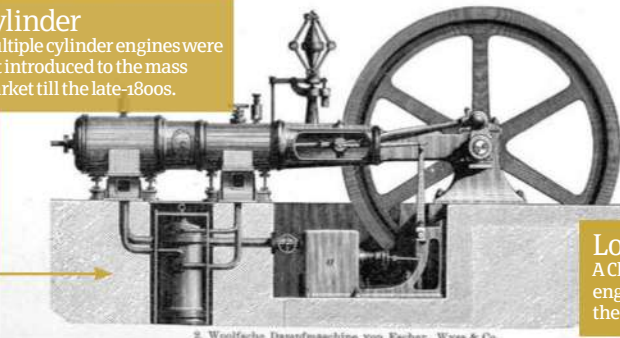
Large, static steam engines powered machinery in mills, mines and factories.



1. Typus einer legenden Einsylindermaschine (Salzstreuung).

Cylinder

Multiple cylinder engines were not introduced to the mass market till the late-1800s.



2. Woolfsche Dampfmaschine von Escher, Wyss & Co.



A late 19th-century steam-powered fire engine.



Loco

A Class C steam locomotive. Steam engines powered the trains during the Industrial Revolution.

© Imcelhiney



Plastic (1856)

From celluloid and Bakelite to nylon and PVC, plastics have many uses

Alexander Parkes (1813-1890) of Birmingham, UK, unveiled the first man-made plastic, Parkesine, at the Great International Exhibition, London, in 1862. A mixture of chloroform and castor oil, it was mouldable but retained its sturdy shape when cooled, giving an advantage over more brittle storage materials. His invention led to the creation of more plastics that wouldn't find widespread commercial success until the 20th century. Parkes's attempts to reduce costs and mass-produce the plastic resulted in his company going under due to poor product quality.

A few years later, American inventor John Wesley Hyatt set about making the first synthetic man-made plastic. By 1870 he and his brother acquired a patent for their plastic, which had more applications than Parkesine. Created by mixing pressurised alcohol, camphor and solid nitrocellulose, it could be reheated repeatedly to mould into different shapes, but was solid enough at room temperature to be sawed and drilled. They named it celluloid, and used it for everyday items like piano keys and combs. Today, it has largely been replaced by more versatile plastics like Bakelite and cellulose acetate due to its flammable nature.

What is a plastic?

A plastic is a material that can be moulded into almost any shape without springing back to its original shape or breaking easily, like rubber or clay respectively. Plastics are polymers, a collection of chemical links known as monomers (with 'poly' meaning 'many').

“ They created it by mixing pressurised alcohol, camphor and solid nitrocellulose ”

Polytetrafluoroethylene (PTFE)

Uses: Non-stick cookware
Fact: Not one you'd want in a spelling bee, PTFE is also known as Teflon and was discovered by DuPont chemist Roy Plunkett in 1938.

Polymethyl methacrylate (PMMA)

Uses: Shatterproof windows
Fact: This transparent and rigid plastic retains its properties even after prolonged exposure to the Sun and weather, making it an excellent substitute for glass in windows.

Polyethylene (PE)

Uses: Plastic bags, milk bottles, toys
Fact: It is the most widely used plastic in the world, with more than 80 million tons produced per year.

Polypropylene (PP)

Uses: Bottles, toys, lunchboxes
Fact: Italian chemist Giulio Natta and his assistant Paolo Chini discovered it in 1954.

Phenol formaldehyde

Uses: Appliance handles, wood adhesive
Fact: Leo Hendrik Baekeland's patent for phenol formaldehyde (trademarked as Bakelite) in 1907 is regarded as the start of the modern plastics industry.

Polycarbonate

Uses: Compact discs, sporting equipment
Fact: Polycarbonate lenses are often used in prescription glasses because they are highly durable and can bend light easily according to need.

Polyvinyl chloride (PVC)

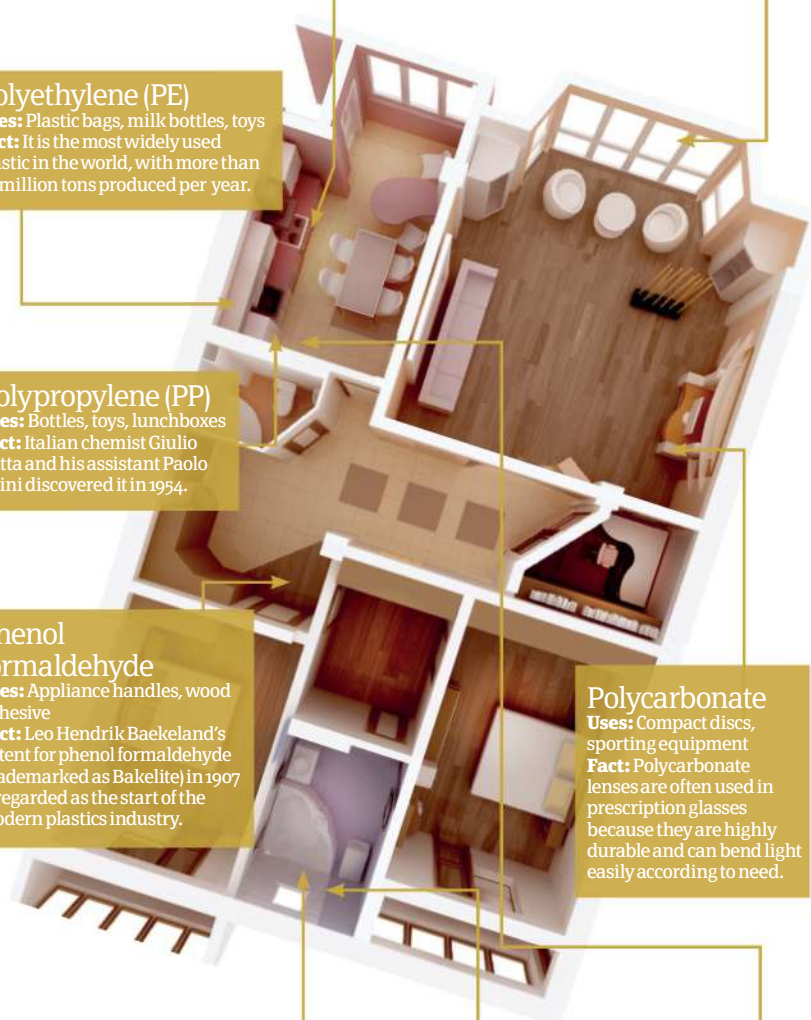
Uses: Garden hoses, shower curtains
Fact: Pure PVC is useful for its rigidity and low flammability; domestic uses include pipes and window frames.

Polystyrene

Uses: Insulating food containers
Fact: Foamed polystyrene in food packaging is useful for its good water-vapour transmission.

Polyacetal

Uses: Shower heads, zips
Fact: Polyacetal is strong, has low friction and is highly resistant to oils and solvents, making it a useful replacement for metal.



Speak and listen

The mouthpiece of Bell's telephone doubled as an earpiece, but the two were separated in later designs.

Wires

Bell's first telephone transmitter, patented in 1876, used existing telegraph wires to send and receive sound.

Smartphone

The telephone soon turned mobile, with many now choosing a smartphone.

Simplicity

The modern mobile phone bears little resemblance to the first telephone, with its slick design.

Telephone (1876)

The invention that changed communication forever

In the 1870s, inventors Alexander Graham Bell and Elisha Gray both developed devices that could transmit voice electronically, the telephone. Amazingly, both men finished their designs within hours of one another, and both rushed to the patent office to have their invention verified as the original. Ultimately, it was Bell who arrived first, and is now credited with the invention, although Gray challenged this assertion for quite some time.

By 1876 Bell had devised a method to talk via electricity, which he marketed as the telephone. His invention was much more successful than attempts by other people to create something similar, and he ultimately wound up victorious as the true inventor of the telephone. This was partly due to his previous experience with the telegraph, which was a wire-based electrical system much like the telephone. Bell's prototype 'harmonic telegraph' showed that sounds of different pitch could be sent across a telegraph, providing the basis for his work on the telephone. He uttered the first words by telephone on 10 March 1876 to his assistant Thomas A Watson: "Mr Watson, come here, I want you."



Airplane (1903)

How the Wright brothers designed and flew the first heavier-than-air vehicle

On 18 September 1901, 33-year-old businessman Wilbur Wright addressed a group of Chicago engineers, outlining the difficulties he and his brother Orville had encountered when trying to achieve heavier-than-air flight. While hot air balloons and gliders had taken to the air in the preceding century, no one had yet built a working plane that could power its own flight. Wilbur's speech provided the basis of the Wright brothers' work over the next decade to build what had previously seemed impossible: an airplane.

The Wright brothers were heavily influenced by the work of predecessors like George Cayley and Otto Lilienthal, but initially focused their efforts where others had not, specifically avoiding further development of wings. "Men already know how to construct wings," explained Wilbur in 1901. However, they

soon changed their mind when it became apparent that wing design had not been perfected, and in 1902 they constructed the Wright glider to test out their biplane wing design. The Wright glider flew at the Kill Devil Hills, near Kitty Hawk on the Outer Banks of North Carolina. By 24 October 1902 they had completed up to 1,000 flights with the glider, with some flights covering almost 190 metres (623 feet) in 26 seconds.

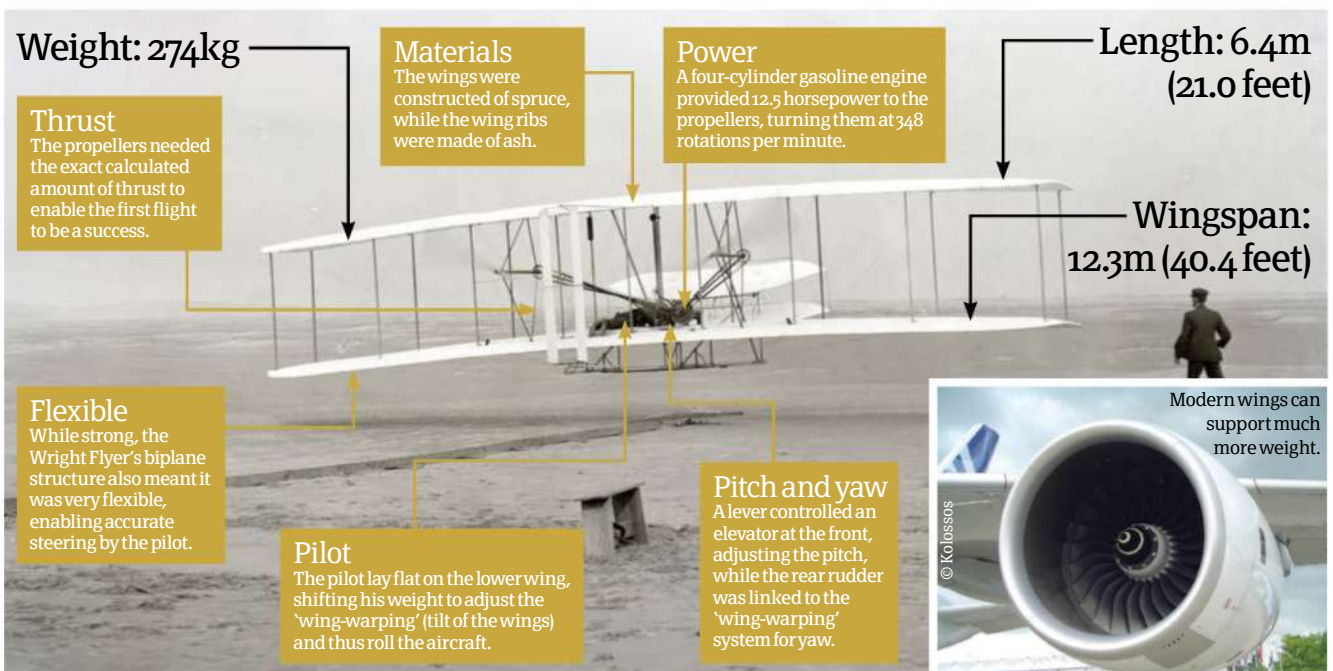
The problem with achieving powered flight in the 19th century and before had been the lack of a suitable source of power. Various experimental craft had toyed with steam power and even gunpowder, but most either didn't have the power to lift the aircraft off the ground or resulted in it breaking apart under pressure. The emergence of the internal-combustion engine in 1860

would prove pivotal. By the early 1900s the engines were much lighter and more powerful, and by 1903 the Wright brothers had the engine they required.

On 17 December 1903, after a failed attempt three days earlier, the Wright Flyer took to the skies, the first powered airplane controlled fully by a pilot to become airborne. Its first flight, piloted by Orville, travelled 36.6 metres (120 feet), and lasted just a few seconds. Kitty Hawk is a notoriously sandy area, so to achieve flight the plane travelled down a monorail track 18 metres (60 feet) in length, consisting of four two-by-fours. One year later, Wilbur flew an improved Flyer II for five minutes.



The Wright brothers' three-axis control system heavily influenced modern planes.



Television (1926)

From humble origins to the most popular entertainment appliance on Earth, the television has connected societies and disseminated information

Disco

The coloured spinning disk from John Logie Baird's 1928 colour television.

HD and 3D

Super high-definition and 3D televisions are sold worldwide. The majority of Western nations switch to a digital-only transmission.

Electronic

The first wave of televisions to go mainstream were all-electronic systems, using a cathode-ray tube to paint images on their phosphorescent screens.



“Television? The word is half Greek and half Latin. No good will come of it”

Described in function as early as 1880 by French engineer Maurice LeBlanc in the journal *La Lumière électrique*, and later named by fellow Frenchman Constantin Perskyi in 1900, the television was seen by many during its early development as a total waste of time, money and resources. Indeed, the editor of the *Manchester Guardian*, England, famously said, “Television? The word is half Greek and half Latin. No good will come of it.”

Despite this scepticism from some, the vision of being able to transmit pictures live over large distances, continued to drive development into the Twenties. This was the decade when two major breakthroughs were achieved. In 1922 American inventor

Charles Francis Jenkins successfully sent a still picture by radio waves and then later, in 1925, Scottish inventor John Logie Baird successfully transmitted a live human face on his custom-built system. For this, Baird is now considered as the inventor of the modern television and, furthermore, also the inventor of colour television, with him releasing a colour variant in 1928.

Baird's colour television was a hybrid of the earlier mechanical prototypes – based on the scanning of an image line by line by light source, a process that caused transmitted images to flicker badly – that had been developed and the later fully electronic systems. The television generated images by using a cathode ray tube in conjunction with a

revolving disc fitted with coloured filters. The system worked by filtering the disc's hues at the transmitting camera and then applying them over the cathode ray tube at the receiver end, generating a primitive colour picture to the viewer. Later, fully electronic systems eradicated the need for a spinning coloured disc by using cathode ray tubes to ‘paint’ images on a glass screen that had been coated in phosphorescent materials.

Based on these principles, the television was iterated upon feverishly during following decades, introducing increased image resolution, greater image refresh rate and more natural and diverse colour palettes. Today the manufacture of televisions is a multibillion-dollar industry.



Touch screens have revolutionised the way we control appliances.

Touch screens (1965)

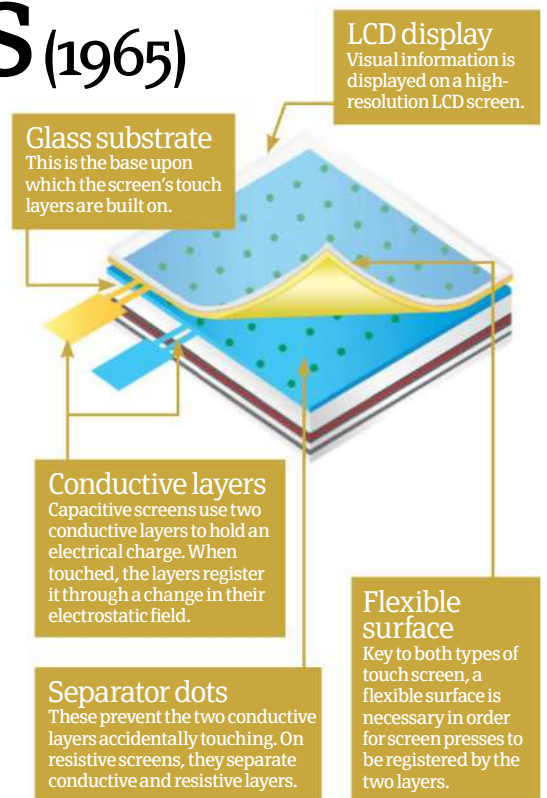
Altering how we interact with the world, they allow direct control of information appliances

Touch screens, invented by English engineer EA Johnson in 1965, are a key feature of the majority of cutting-edge electrical appliances; an integral part of people's day-to-day lives, streamlining their relationship with computer software and hardware and banishing clunky peripheral control devices.

There are two types of touch screen: resistive and capacitive. Resistive touch screens work by registering pressure from the user's finger or stylus by the conjoining of a conductive and resistive layer within the screen. When the screen is pushed, the electrically charged

conductive layer touches the resistive layer at that point, causing an alteration in the current. This is detected by a controller unit, which logs the touch event's vertical/horizontal co-ordinates and action.

Capacitive touch screens work by coating an insulator with a transparent conductor. When the screen is touched by another electrical conductor, like a human, its electrostatic field is distorted at the point of contact. This is registered by a control unit via oscillator circuits at the four corners of the screen, which vary in frequency depending on where the touch took place. This data is then translated into X/Y co-ordinates.

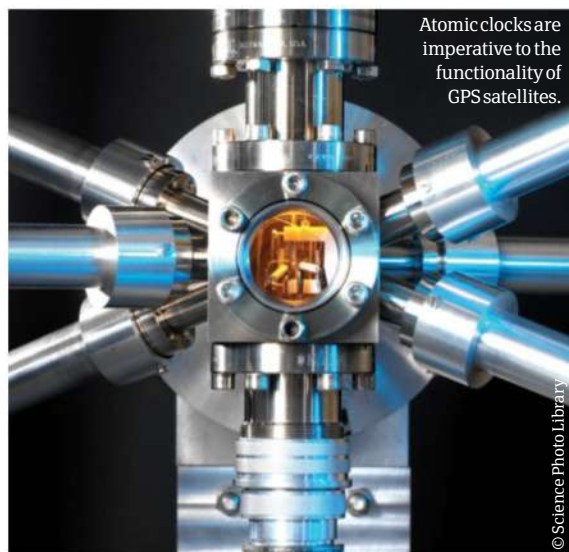


GPS (1973)

Without it, we'd be lost

In the Seventies, the US military asked Americans Ivan Getting and Professor Bradford Parkinson to devise the first GPS system so that they could fire missiles accurately and avoid risk of attack. Their proposal was a network of radio transmitters, with each having an in-built clock. These would be atomic clocks, allowing each satellite to have a precise measure of time. Each missile had a radio emitter and receiver, and by firing signals at the satellites they were able to measure how long it took the signal to return and pinpoint their location. This is the basis of GPS today.

The first GPS satellites were launched by the US military in 1978, but public access was denied until the early-Nineties. GPS satellites orbit at a height of 20,200 kilometres (12,500 miles) above the surface, allowing them to provide cover at all times. Originally there were 18 satellites in 1979 and then 24 in 1988, with three of those as replacements on standby, but that number is now closer to 30.

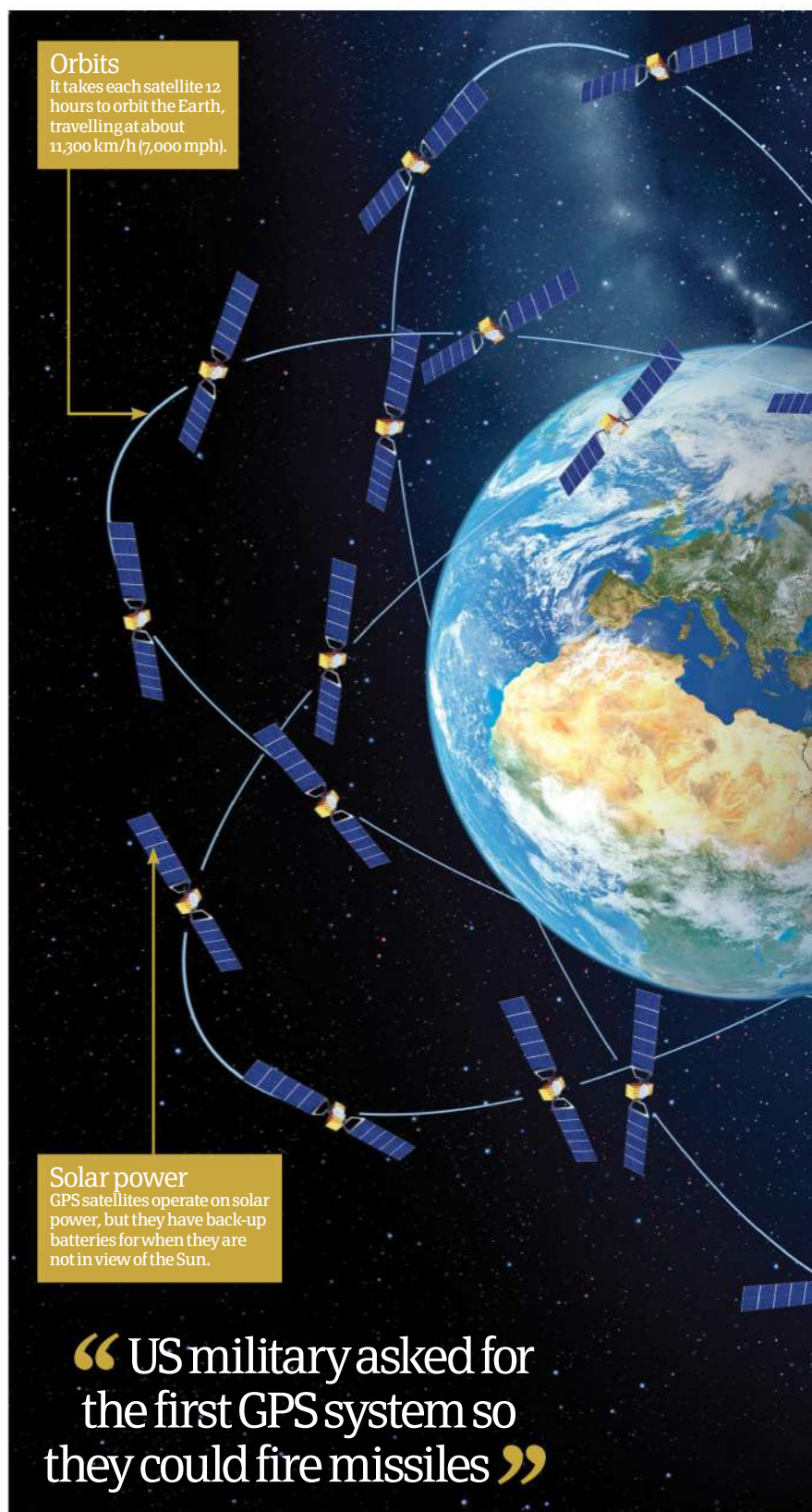


Atomic clocks are imperative to the functionality of GPS satellites.

© Science Photo Library

Atomic clocks

A major contribution to GPS invention was advancement of atomic clocks. Providing accuracy to within a billionth of a second, they allowed the satellites to be accurately tracked and relay information above Earth and back again, providing pinpoint locations for various devices.



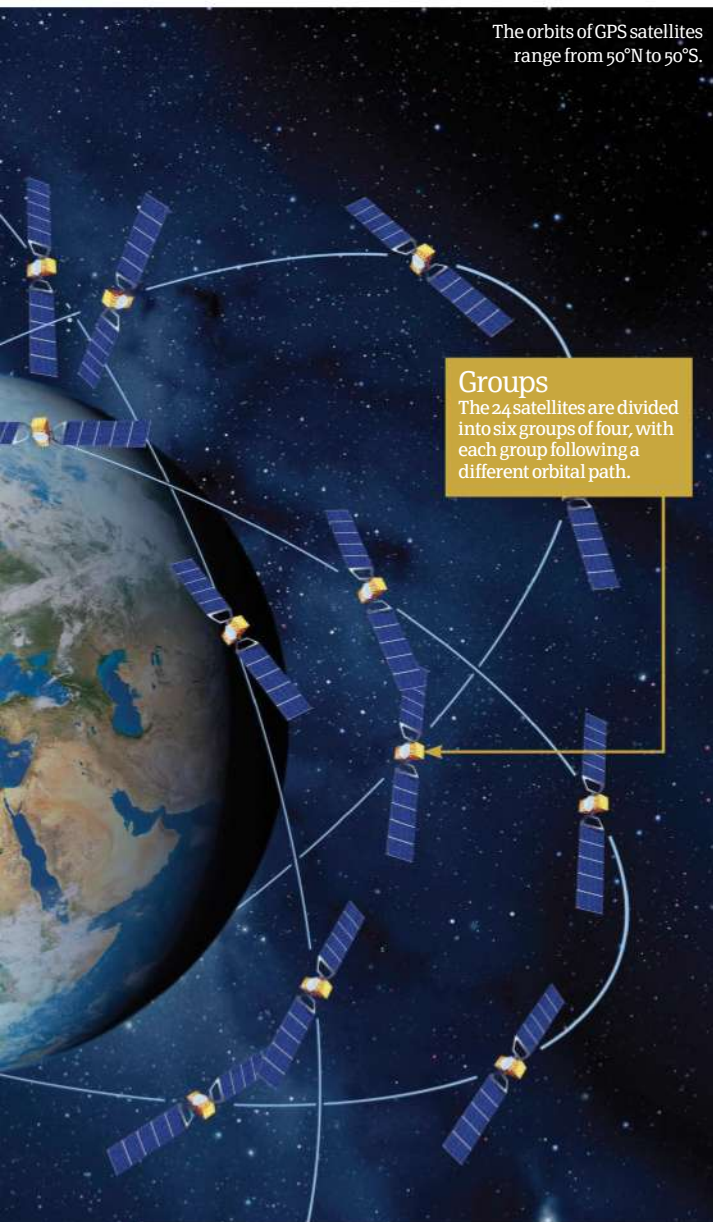
Orbits

It takes each satellite 12 hours to orbit the Earth, travelling at about 11,300 km/h (7,000 mph).

Solar power

GPS satellites operate on solar power, but they have back-up batteries for when they are not in view of the Sun.

“US military asked for the first GPS system so they could fire missiles”



Today we use GPS in many devices, including satnav.



The Internet and WWW

(1960s & 1989)

How global communication became simple, easy and instantaneous

While some firms had local networks in the early-Sixties, there was no host-to-host connection until 1969, when the Advanced Research Projects Agency (ARPA) of the US Department of Defense created ARPANET. The first data exchange over this network resulted in the computers crashing when researchers tried to simply send the letter 'g'. However, it was soon up and running at four computers across the US.

While the Internet was working by the Seventies and Eighties, and spreading, it was nothing like we know it today. It focused on the backbone of computer operations, data the user wouldn't see. In the late-Eighties, a researcher at CERN called Tim Berners-Lee and his colleagues developed a system through which users of the Internet would be able to access text-based 'pages', which would later become websites (the world wide web). Their system involved the use of HyperText Transfer Protocol (HTTP), allowing communication between network servers and computers. They developed an early web browser that allowed users to navigate these text pages, which was released to the public in 1992. The first 'point and click' graphical interface browser arrived a year later from Marc Andreessen (co-founder of Netscape) at the University of Illinois, and was called Mosaic.



Archimedes

(c.287 BCE–c.212 BCE)

The greatest and best-known inventor of the ancient world was also one of its greatest mathematicians, and this was Archimedes of Syracuse. Fortunately, a great deal is known about his mathematical achievements from his own writings, however, any knowledge of his remarkable inventions exists only because his contemporaries documented them.

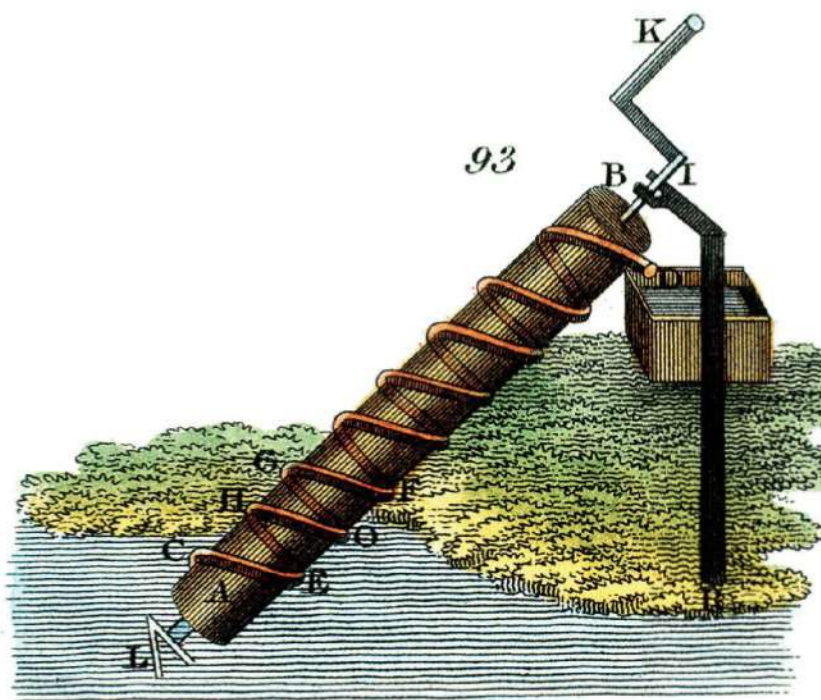
Archimedes was born in Syracuse, on the island of Sicily, then a colony of the Grecian Empire. Little is known about his life or what kind of person he was. The little that is known comes from commentaries written by historians who lived at the time or over the next hundred or so years. The most important source is Greek-born Greek and Roman biographer and historian Plutarch (c.46–120 CE).

According to Plutarch, Archimedes's father was an astronomer and the family was closely related to the ruler of Syracuse, King Hiero (also spelled Hieron) II (c.306–215 BCE). The king's reign endured almost as long as Archimedes's



'Archimedes
Thoughtful'
by Domenico Fetti,
1620, oil on canvas.





Above: An 1815 print showing the inside of an Archimedes Screw, normally housed in a cylinder. Turning the handle clockwise drags the water up the screw thread, through the cylinder, so that it emerges at the top. The device was used extensively for irrigation in Archimedes's day, and brought him great fame.

entire life – and many of Archimedes's activities were connected to Hiero.

King Hiero asked Archimedes to design a pump to drain his ship during the voyage to Alexandria, Egypt. Archimedes devised a simple but brilliant solution. The device, today known as the Archimedes Screw (or Archimedean Screw) consists of a helical blade – a wide screw thread – inside a cylinder. The screw lifts water when it turns, and was so effective that it was quickly adopted in many countries for irrigation. Archimedean Screws remain commonplace today in factories and on earth-moving machines, where they are used to move granular materials such as soil and plastic pellets. They are also still in use for irrigation worldwide.

Mathematics

Archimedes brought together mathematics and experimental and mechanical principles, and clearly realized the close and important connection between them. He studied the mathematics of the day – in Alexandria – and

“Archimedes brought together mathematics and experimental and mechanical principles”



Block and tackle

Ancient civilizations made use of what physicists call 'simple machines': the lever, ramp, wheel and axle; inclined plane, wedge and pulley. Archimedes was almost certainly the first to combine two pulleys, to make a device that could exert a huge force. That device, the block and tackle, is used today for lifting or pulling heavy loads.

According to Plutarch, Archimedes invented the block and tackle in response to a challenge set by King Hiero after Archimedes had suggested that there is no weight too great to be moved by a lever. Hiero challenged Archimedes to move the huge and heavy ship Syracusia, a feat normally only achieved by teams of many strong men. Archimedes single-handedly moved the ship, complete with crew and cargo, not with a lever but with a block and tackle.

quickly moved beyond it. It is his exquisite mathematical proofs and inspired ideas that reveal his true genius.

Although none of Archimedes's original work in his own hand exists, there are several copies made during the first thousand or so years after his death. The most important is an 11th-century manuscript on vellum. Archimedes's work had been scraped off, overwritten with Christian prayers, and bound together as part of a book. Since this book, now called the *Archimedes Palimpsest*, was bought at auction in 1998, scientists have been applying the latest imaging techniques to try to 'see through' the Christian text to enable them to read Archimedes's work for the first time. One of the most remarkable findings from the analysis of this book is that Archimedes invented some of the principles of the mathematical technique today called calculus. Crucial to modern science and technology, calculus was only actually formalized in the late 17th century, by Isaac



Left: An ancient Roman mosaic depicting the death of Archimedes. The mosaic was uncovered early in the 19th century during French excavations of Pompeii, Italy. It shows Archimedes at his table with an abacus – and a Roman soldier apparently telling Archimedes to leave the room.

Below: Part of the Antikythera mechanism, which appears to be an ancient astronomical calculator and was recovered from the wreck of a Roman ship dating to the first century BCE. Archimedes is known to have built devices for this purpose and many academics believe this could be one of them.



Newton (1643–1727) and Gottfried Leibniz (1646–1716).

Archimedes used applied mathematics, calculating the centres of gravity of objects and working out the mathematics behind 'simple machines' like levers, pulleys and gears.

He used his knowledge of gears to invent a small, wheeled cart that could measure long distances (an odometer), a clock that struck the hours, and devices to predict the positions of the sun, the moon and the five planets that were then known. In 1900, divers discovered what scholars deduced was an ancient astronomical computer in a wreck off the coast of the Greek island Antikythera. Some historians believe that this computer may be closely descended from the work of Archimedes.

Of all Archimedes's inventions, the ones most celebrated in his lifetime were the weapons he designed to defend Syracuse during the siege of the city by the Romans, which began in 214 BCE. The weapons included the Claw – a crane fixed to the city wall that could lift Roman ships out of the water and drop or capsize them.



Above: The Archimedes Palimpsest – a book of Christian prayers (horizontal) written in the 12th century over a tenth-century copy of some of Archimedes's most important works (vertical). Scientists at the Walters Art Museum in Baltimore, USA, have used a variety of techniques to make the Archimedes text more visible.



al-Jazarī

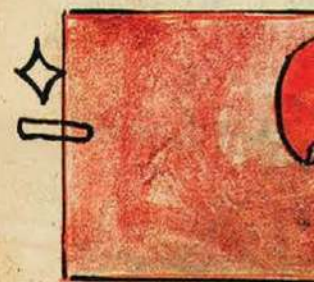
(1136–1206)

Most people are aware of the tremendous scientific and technological advances of the great ancient civilizations in Egypt, China, India, Greece and Rome. However, during the Middle Ages, the Islamic Empire kept the spirit of learning and innovation alive. One of its greatest technical geniuses was a mechanical engineer named al-Jazarī.

Badi' al-Zaman Abu al-'Izz Isma'il ibn al-Razzaz al-Jazarī was born in an area of Mesopotamia called al-Jazira, in what is now part of modern-day southern Turkey. al-Jazarī lived at the height of the Islamic Golden Age, also sometimes called the Islamic Renaissance. The spread of Islam in the seventh century had encouraged a rich culture and a stable political system – the Caliphate. By 750 CE, the Caliphate covered a huge area, from northern Spain in the west, through the Middle East and North Africa, to the fringes of China in the east. Throughout this Islamic

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للفن صمد ثمار مد الحلو

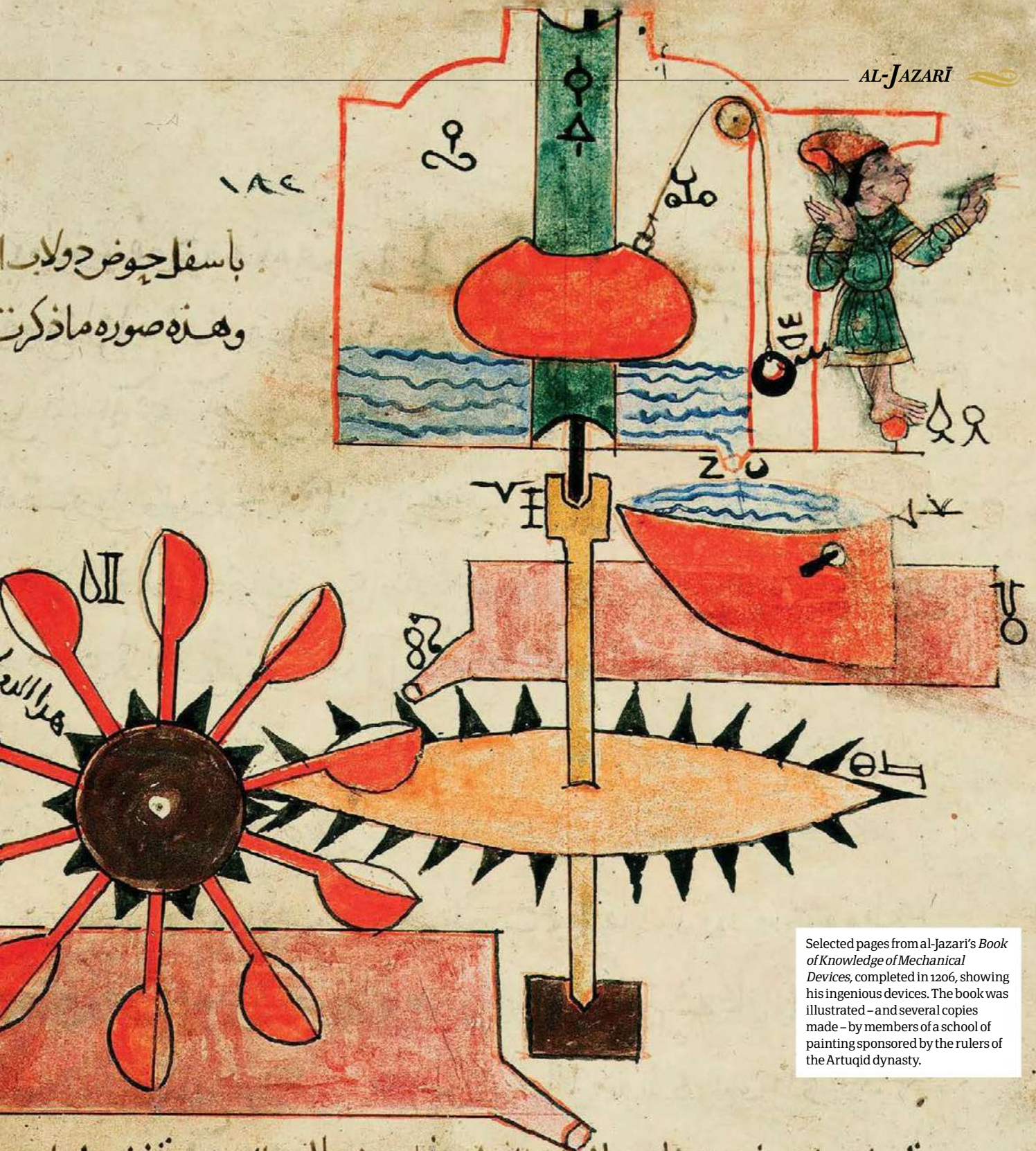


هذا المحور من

ولكن هذا القوس

ضيق من الانبوب

١٨٤
باسفل حوض دلاب
وهذه صورة ما ذكرت



Selected pages from al-Jazari's *Book of Knowledge of Mechanical Devices*, completed in 1206, showing his ingenious devices. The book was illustrated – and several copies made – by members of a school of painting sponsored by the rulers of the Artuqid dynasty.

ثم يتخذ دلاب ذو كفات كالدراب الاول وفي حوض الحوض الاول ويتخذ على طرف
الدراب قرص قطره طول الاصبع وعلى محيطه دندانات بعد ما ينهن بهد سوي
خارج عن الحوض على طرف المحور ويخترق في وسط ارض هذا الحوض ثقب سعته ا



Above: Reconstruction of al-Jazari's elephant clock at the Ibn Battuta Mall in Dubai, United Arab Emirates. Every half-hour, the scribe on the elephant's back rotates full circle, and at the end of each half-hour, the figure of the mahout (elephant driver) beats a drum and a cymbal sounds.

Empire, there was a great emphasis on learning; scholars collected and translated all the knowledge they could from around the world and added their own. From the ninth to the 12th century, the Caliphate was the foremost intellectual centre of the world.

Out of the stability and the learning came great wealth, and powerful dynasties ruled over each region. al-Jazari became chief engineer to the Artuqid dynasty in the town of Diyar Bakir, after his father retired from the same position in 1174. Most of what we know about al-Jazari comes from a book he completed shortly before his death. The *Kitab fi ma'rifat al-hiyal al-handasiyya* (*Book of*



Above: Glass alembic, approximately 11th century. An alembic is an essential tool in distillation, a procedure for purifying mixtures. Distillation was pioneered by Islamic chemists, who developed many processes that would later be important in the development of the science of chemistry.

Knowledge of Mechanical Devices) is a compendium of the engineering designs he created through his career. According to the book's introduction, Nasir al-Din Mahmud ibn Muhammad, the dynasty's ruler between 1200 and 1222, commissioned al-Jazari to write the book in 1198. al-Jazari's book contains details of 50 ingenious devices, including intricate clocks, fountains that regularly change their flow patterns, machines for raising water and toys for entertainment. The description of each device is accompanied by clear drawings that help explain how it was constructed and how it worked.

Engineering

The spread of Islam brought huge advances in science, mathematics, medicine and philosophy. Engineering, on the other hand – although held in great esteem and practised competently – was mostly just a continuation of existing technologies established by the Greeks and the Romans. There were certainly notable exceptions, and some of those innovations are to be found in al-Jazari's wonderful book. For example, al-Jazari's water- or donkey-powered devices made use of power-transmission elements that had been used for centuries: gears, levers and pulleys. But in one of his inventions, a double-acting piston pump, he gives the first known reference to a crankshaft – a device for changing rotary motion to back-and-

The influence of islamic scholars

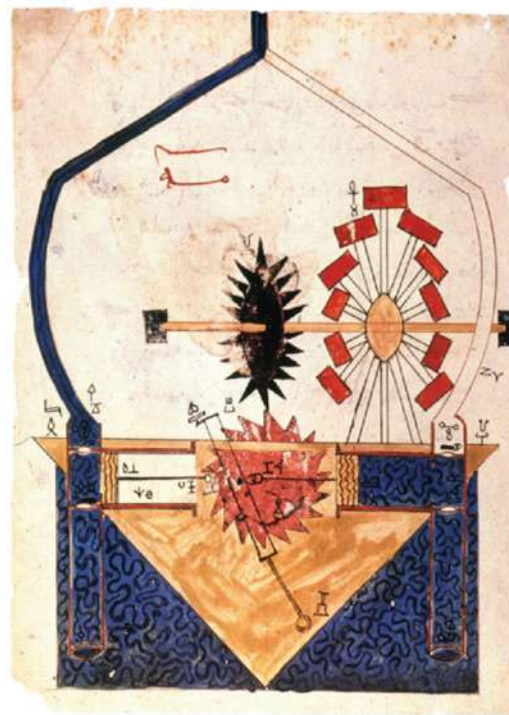
During the Islamic Golden Age, the centre of scholarly activity was the House of Wisdom in Baghdad (in modern Iraq). Both a library and a centre for translation, the House of Wisdom acted not only as a repository for the books and ideas of ancient thinkers from Greece and China, but also as a centre of excellence for contemporary scholars.

Much of the knowledge collected, translated and expanded by medieval Islamic scholars passed into Europe in the twelfth and thirteenth centuries. A dedicated band of European scholars sought out works in Spain and Sicily after these areas came under Christian rule. They translated what they found into Latin, and the resulting documents formed the basis of early scientific study in Europe.

The works of the Islamic scientists, mathematicians, astronomers and



doctors contained significant advances in fields such as atomic theory, optics, surgery, chemistry and mathematics. Kept alive in the universities of medieval Europe, their ideas inspired the Scientific Revolution of the sixteenth and seventeenth centuries.



Above: Water-raising pump from the *Book of Knowledge of Mechanical Devices*. Pistons driven by a water wheel open and close valves, drawing water from the river (blue) and pushing it up through the two pipes, which join to form a single pipe (top).

forth motion (or vice versa). He also makes extensive use of the camshaft, a rotating cylinder with pegs protruding from it; his is the first mention of that, too. al-Jazarī also invented the first known combination lock and the earliest known mechanical water-supply system, which was installed in Damascus in the 13th century, to supply hospitals and mosques across the city.

Several of al-Jazarī's contraptions featured automata: animal or human figures that made precise, programmed movements. For example, he describes a boat containing four automated musicians that entertained at parties and an automated girl figure that refilled a wash basin. Automata also feature in most of al-Jazarī's clocks, which were more elaborate and ingenious than any that had come before. Most impressive was his 'castle clock'. More than 3 metres (10 feet) high, it displayed the constellations of the zodiac, with the orbits of the Sun and the Moon, and doors that opened every hour to reveal papier-mâché figures. This extraordinary device could also be programmed to take account of the varying day lengths.



Above: Model of a blood-letting device described in al-Jazarī's *Book of Knowledge of Mechanical Devices*. It measured the volume of blood lost during blood-letting sessions.



Above: Model of pump built for a 1976 exhibition called 'Science and Technology in Islam' at the Science Museum, London, part of the countrywide Festival of Islam.



Johannes Gutenberg

(c.1400–3 February 1468)

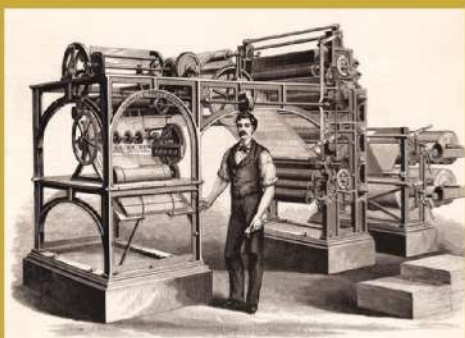
It is rather difficult to overestimate the importance of the printing press in the history of the world. The mass-production of books made them cheaper and far more accessible, which promoted literacy and the spread of ideas. The creator of this influential new technology was a German goldsmith who was called Johannes Gutenberg.

Very little is known of the early life of Johannes (or Johann) Gutenberg. It is known that he was born in Mainz in Germany around 1400, and that he came from the privileged, governing elite. He attended university, where he would certainly have come into contact with books, and he trained as a goldsmith.

Around 1420, several families were exiled from Mainz after a rebellion by the tax-paying middle class. Gutenberg's was among them, and he travelled to Strasbourg, where he was involved in several ventures. One of them, he told his financial backers, was 'a secret'. It is very likely



Gutenberg in a
16th century
copper engraving.



Rotary printing press

Although Gutenberg's invention dramatically changed the course of history in a very short time, printing was still a painstaking process. It required several people and produced only a hundred or so sheets per hour. The invention of cast-iron presses and the introduction of steam power in the 19th century improved that rate to about a thousand pages an hour. A further major step in the history of printing was the invention of the rotary press in 1843, by American inventor Richard March Hoe (1812-1886).

Hoe's steam-powered invention could print millions of pages per day, largely due to the fact that paper could be fed in through rollers as a continuous sheet. Hoe's device relied upon lithography, a process invented by Bavarian author Aloys Senefelder (1771-1834). In lithography, ink is applied to smooth surfaces rather than to raised type, which was ideally suited to the drum of Hoe's press.

that this secret was the development of the printing press.

At the time, nearly all books were painstakingly written out by scribes. Books, therefore, were rare and extremely expensive, and literacy was confined to religious and political leaders. Woodblock printing produced a few books – but each block, representing a whole page, had to be carved in its entirety. Gutenberg's important innovation, 'moveable type', changed all that.

Moveable type

Moveable type is a system of printing in which a page of text is arranged in a frame, or matrix, by slotting in individual raised letters. The letters are then inked and pressed onto paper. It was invented in Korea and in China in the 11th century, but never caught on, mostly because of the large



Above: The frontispiece of the oldest dated printed book. Bought from the monk in a cave in Dunhuang, China in 1907, this copy of the Buddhist text Diamond Sutra is on a scroll 5 metres (16 feet) long. It was printed using woodblocks in 868 CE.



number of characters that are used in written Chinese and Korean.

Gutenberg invented moveable type independently, and his approach was simple and efficient. First, he made punches of hardened steel, each with the raised shape of a letter. With these, he punched impressions of the letters into copper. Next, he fitted the 'negative' copper pieces into a hand-held mould of his own invention, and poured in molten metal to cast as many perfect copies of the letters as he needed. The metal Gutenberg was an alloy of lead, tin and antimony that has a low melting point and solidified quickly inside the mould. His alloy is still used wherever 'founder's type' or 'hot metal' letterpress printing methods survive today.

While still in Strasbourg in the 1440s, Gutenberg experimented with another crucial element of his

Above: Coloured 19th-century artist's impression of a scene in Gutenberg's workshop (artist unknown). Gutenberg, bearded, is shown in the foreground, checking a printed page. There would actually have been about 20 people working in the workshop at any one time.

Right: Portrait of German playwright Aloys Senefelder, the inventor of lithography. His process enabled printing of illustrations from a flat surface; artists could draw directly onto it, using special water-repellent inks.



Below: A type case filled with large, decorative moveable type in the Gutenberg Museum. A printer would slot these individual pieces of type into a frame, to represent the text of one page of a book.



printing system: the press. Gutenberg's press was adapted from winemakers' screw presses. The inked, typeset text was slotted face-up on a flat bed, covered with paper, then slid under a heavy stone; turning the screw then pressed the paper onto the type. Repeating the process gave exact copies time after time. Gutenberg also formulated oil-based ink, which was more durable than the water-based inks in use at the time. He knew that by putting all these technologies together he was onto something very important.

By 1448, Gutenberg was back in Mainz. He borrowed money from a wealthy investor, Johann Fust (c.1400–1466), to set up a printing shop there. Knowing that the church would be the main source of business, Gutenberg decided to print bibles. Work on the Gutenberg Bible began around 1452, after several test prints of other works, including books on Latin grammar. The relatively low price of the bibles, and their exquisite quality, secured the success of Gutenberg's new

technology, which then spread quickly across the rest of Europe. By 1500, millions of books had been printed. Gutenberg had created the first media revolution.

Unfortunately for Gutenberg, Johann Fust demanded his money back, and accused Gutenberg of embezzlement. A judge ordered Gutenberg to hand over his printing equipment as payment. Fust went on to become a successful printer, and Gutenberg set up a smaller printing shop in the nearby city of Bamberg. Gutenberg later moved to a small village where, in 1465, he was finally recognized for his invention and given an annual pension. He died three years later in relative poverty.

“The low price of the bibles, and their quality, secured the success of Gutenberg's new technology”



Above: A highly decorated page from a Gutenberg Bible. Gutenberg produced 180 copies of his bible. Some were on vellum, others on paper; some were decorated (by hand), others were left plain. The books caused a sensation when they were first displayed at a trade fair in Frankfurt in 1454.



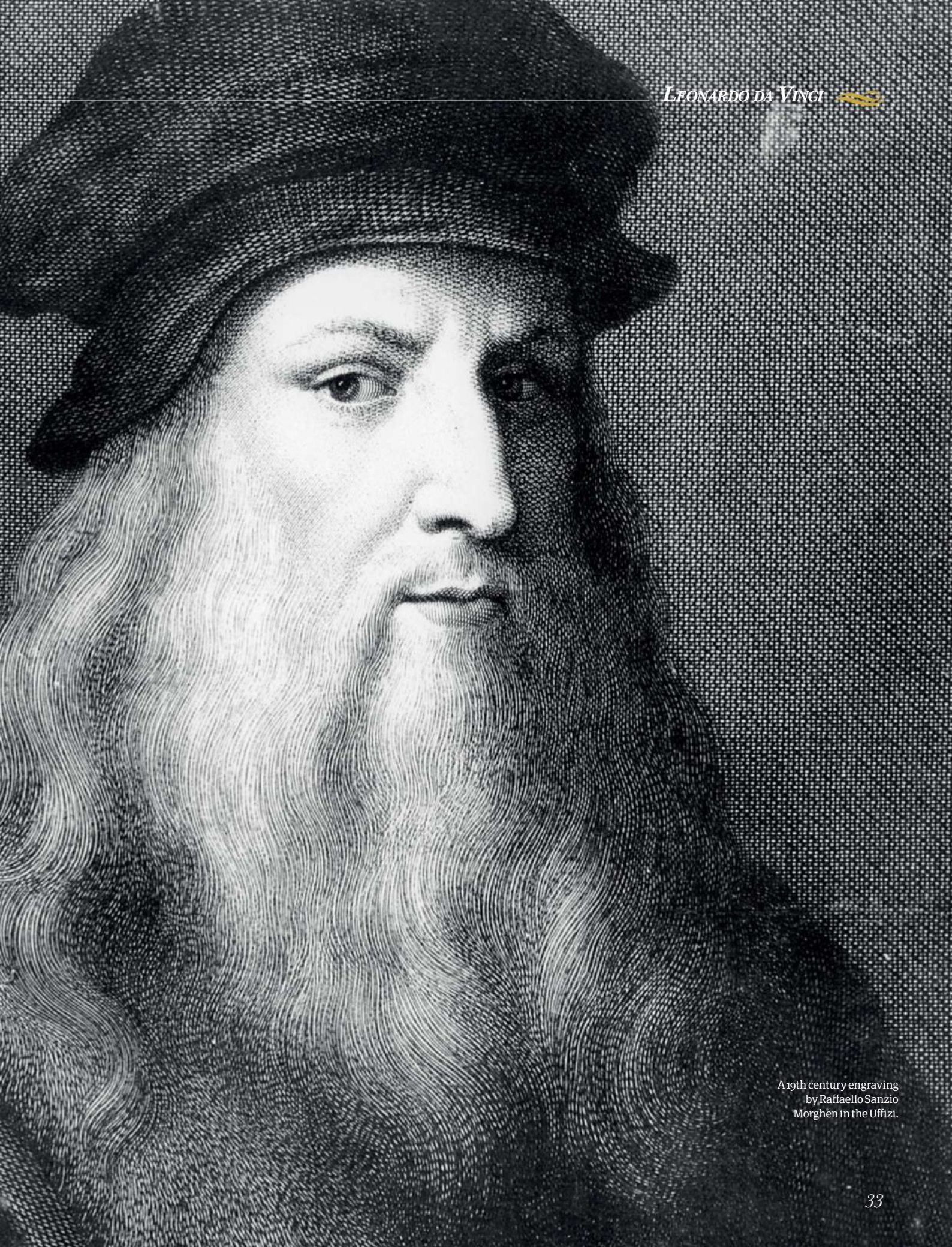
Leonardo da Vinci

(15 April 1452–2 May 1519)

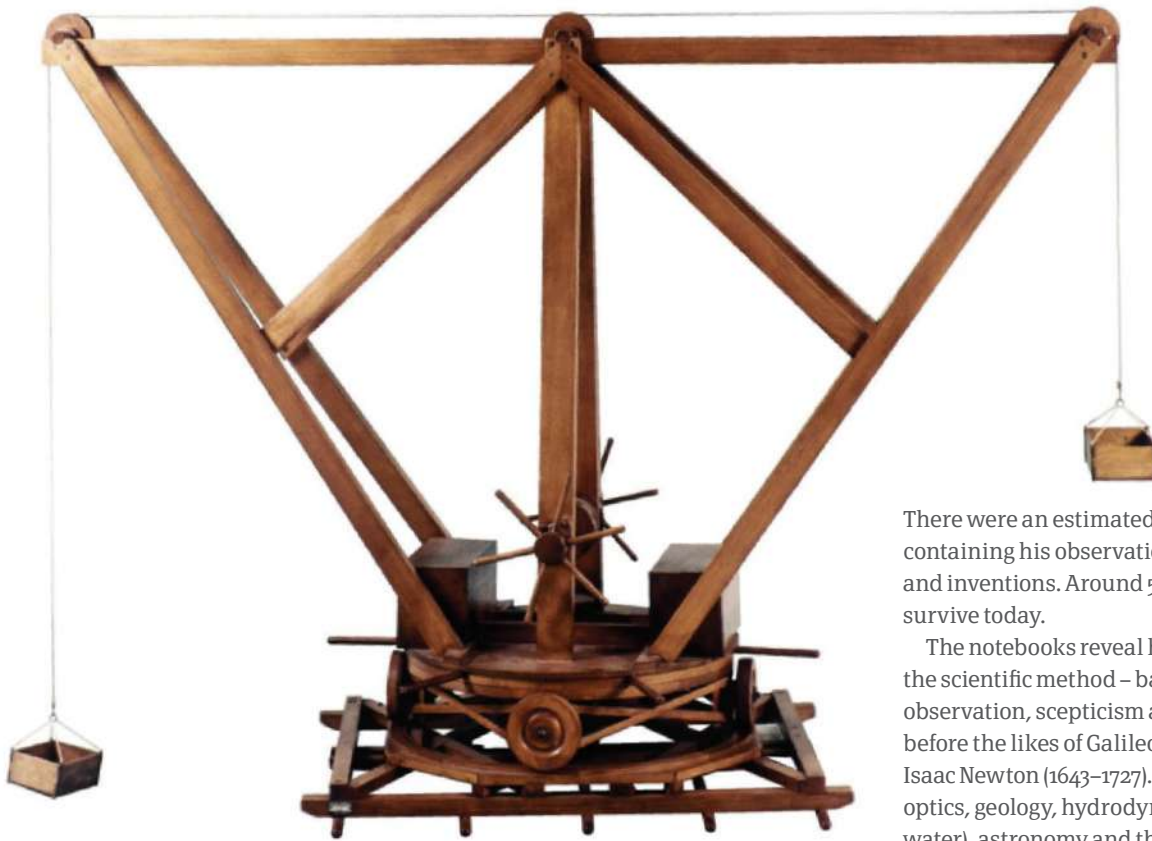
The name Leonardo da Vinci is synonymous with genius, yet arguably the Italian polymath does not belong in this book. He was undoubtedly a genius, and he certainly changed the world, but his influence on history was restricted to developments in art. His scientific researches were not well known in his lifetime, and most of his inventions never built.

Leonardo da Vinci was the archetypal Renaissance man. He had an enormous influence on the development of painting, drawing and sculpture. He was a pioneer of perspective and of using anatomical studies to improve life drawing; he was an innovator in how to paint light and shade, in using new materials and in composition. That Leonardo was also a great scientist, engineer and inventor only became common knowledge when his journals were published long after his death.

Leonardo was born in Vinci, a town in Tuscany, Italy. His father was a local notary, and his mother



A 19th century engraving
by Raffaello Sanzio
Morghen in the Uffizi.



Left: Model of a revolving crane. Leonardo's twin cranes were designed for quarrying. Stones cut from a rock face would be loaded into one bucket; the whole crane would then rotate, and the bucket would be emptied while another was loaded.

Below: Model based on Leonardo's design for a screw-cutting machine. Turning the crank handle causes the dowel in the centre to turn. It turns the two side screws, advancing the cutting tool along the length of the wooden dowel in the centre.

a peasant. At the age of sixteen, he became an apprentice at the workshop of artist Andrea del Verrocchio (c.1435–1488) in Florence, where his talents shone through. He qualified as a master at the age of 20, and worked in Florence, then in Milan, where he created such iconic paintings as *The Adoration of the Magi*, *The Virgin of the Rocks* and *The Last Supper*.

Throughout his life, and particularly during his time in Milan, Leonardo kept detailed notebooks.

There were an estimated 13,000 pages in all, containing his observations, thoughts, sketches and inventions. Around 5,000 of these pages survive today.

The notebooks reveal how Leonardo followed the scientific method – based on careful observation, scepticism and experiment – well before the likes of Galileo Galilei (1564–1642) and Isaac Newton (1643–1727). Leonardo's grasp of optics, geology, hydrodynamics (the behaviour of water), astronomy and the principles behind gears, levers, cantilevers and force and motion was far ahead of his time.

Work experience

Leonardo had a chance to apply some of his knowledge and understanding when he worked as an engineer and military architect for two dukes of Milan from 1485 until 1499, and afterwards in the same capacity for other patrons, including the infamous Cesare Borgia (1475–1507).

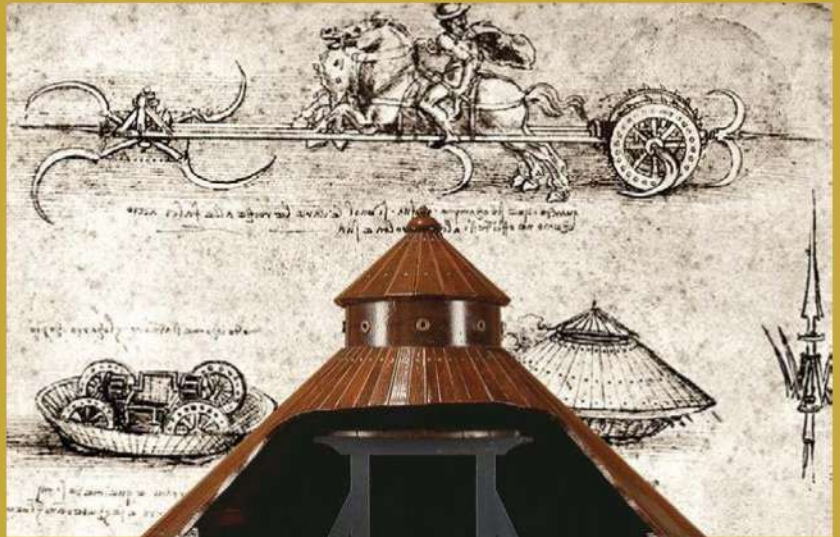


Above: Model of Leonardo's car. He intended it to be powered by spring-driven clockwork. It has no driver's seat, because this was designed to be an automaton. Like most of Leonardo's remarkable inventions, the car was not built in his lifetime.

Leonardo's military inventions

Leonardo da Vinci lived during a turbulent time in Italy's history. In fact, Italy as it is today did not then exist, but was largely a collection of frequently warring city states. In addition, there were constant threats from, and takeovers by, the French and Spanish. Rich patrons would do anything to protect their wealth, status and territories, so when Leonardo suggested he could build terrifying weapons and defence systems, he found willing supporters.

It is ironic that Leonardo should have produced such terrifying, warlike designs, since he was a committed pacifist. Perhaps that is why, in some cases, he seems to have introduced flaws into the designs deliberately, or withheld crucial information, which would prevent them from working. One pertinent example is his design for a tank, sketched out in detail more than four hundred years before any tanks were constructed. Leonardo's tank was to be powered by eight men turning cranks. When the design was built for a television series in 2004, it would not move until one of the gears was reversed, a basic error that was probably intentional, rather than an oversight.



Indeed, when Leonardo was offering his services to these men, he made a point of promising them wonderful engineering projects, and only mentioned in passing that he was also a painter.

Among Leonardo's notebooks were detailed plans for many incredible inventions, most of which were almost certainly never built. These included a huge crossbow, various flying machines, a parachute, an armoured vehicle, a dredging machine, a helicopter, a humanoid mechanical robot, an aqualung, a bicycle and a water-powered alarm clock.

Since the 19th century, there has been great interest in Leonardo among academics and the general public alike. In recent years, several of his inventions that had only ever existed on paper have at last been constructed. Leonardo's designs have been found to work remarkably well, albeit with a bit of adaptation in some cases.

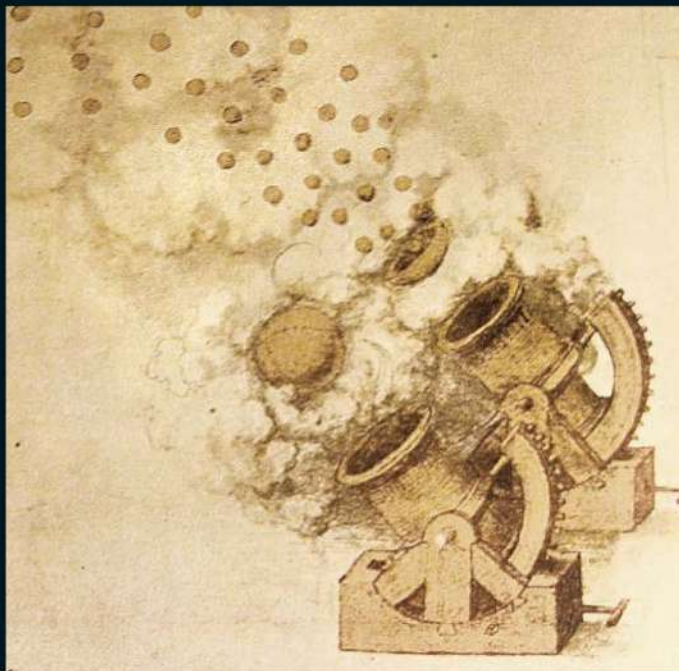
A few of Leonardo's inventions did make it out of his notebooks in his day, and were used by other people, but because there was no patent system in Italy at the time, there is little record of exactly which inventions passed into general use, or how.

“Leonardo was almost unknown for his scientific insight and his remarkable inventions”

Two known examples are a bobbin-winding machine and a lens-grinding machine. Ingenious though they are, these devices do not do justice to Leonardo's enormous genius and foresight.

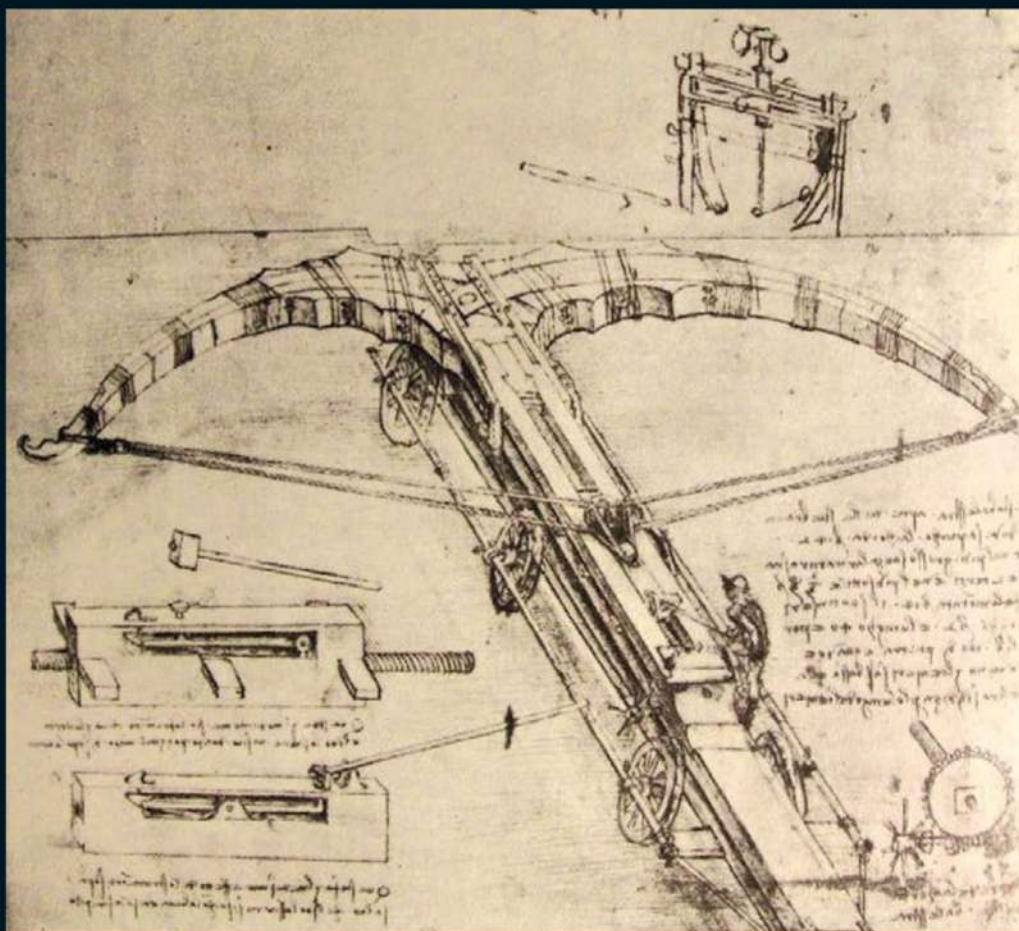
In 1513, Leonardo met the king of France, Francis I (1494–1547), after the king's conquest of Milan. Francis commissioned Leonardo to make him an automaton in the form of a lion. Leonardo made one that walked and turned its head, and even presented a bunch of orchids when stroked in a certain way. Francis was so impressed by this creation that he became Leonardo's patron, and Leonardo lived out the last three years of his life in Amboise, France. There he died peacefully, renowned for his astonishing artistic skill but almost unknown for his scientific insight and his remarkable inventions.

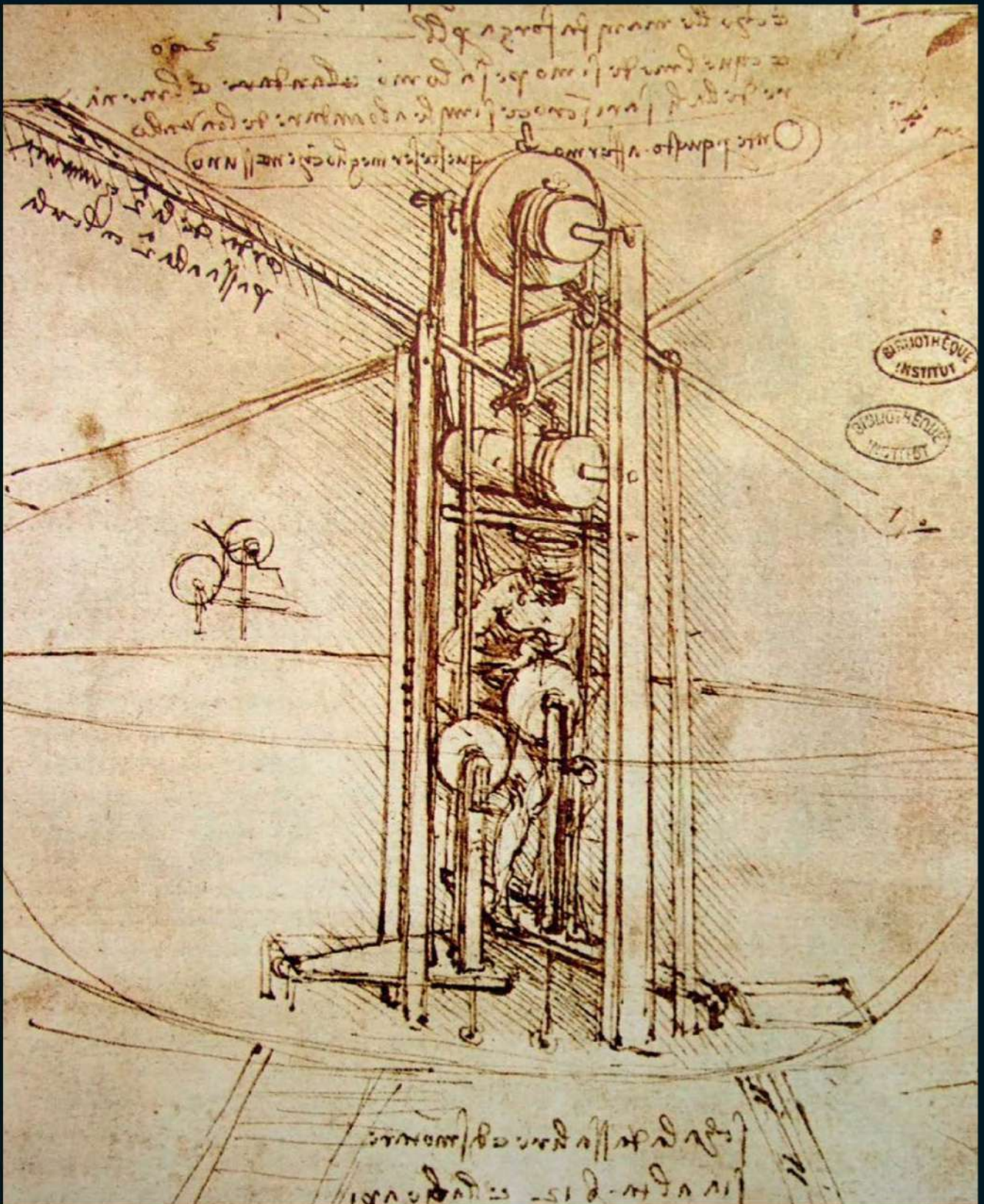
Above: Leonardo's assault tank – a model built by IBM and on display at Château du Clos Lucé, France, Leonardo's final home. The shell of this hand-cranked tank was reinforced with metal plates containing holes so that the soldiers could fire weapons from within. Behind can be seen the sketches he made and on which the model was based.



On this page: Various drawings by Leonardo da Vinci. Including designs for an enormous crossbow, an Artillery Park, and a drawing of Cannons.

Opposite page: Historical drawing of a flying machine designed by Leonardo da Vinci.







Hans Lipperhey

(1570 – September 1619)

The telescope has enabled us to discover our place in the Universe, and to reveal the treasures and sheer scale of deep space. Nobody is completely sure who was the first to construct a practical telescope or whose genius was the first to realize the potential for this device. However, Dutch lens maker Hans Lipperhey was certainly the first to apply for a patent, in 1608.

Hans Lipperhey (sometimes spelled Lippershey) was born in Wesel, Germany, and moved to Middelburg, in the Netherlands (then the Dutch Republic), in 1594. In the same year he married, became a Dutch citizen and opened a spectacle shop in the city. Little is known of his life, but what is clear is that he was the first person to apply for a patent for the telescope, which was called a '*kijker*' (Dutch for 'viewer').

In September 1608, Lipperhey travelled to The Hague, the political centre of the Dutch Republic, where he filed the patent application for his



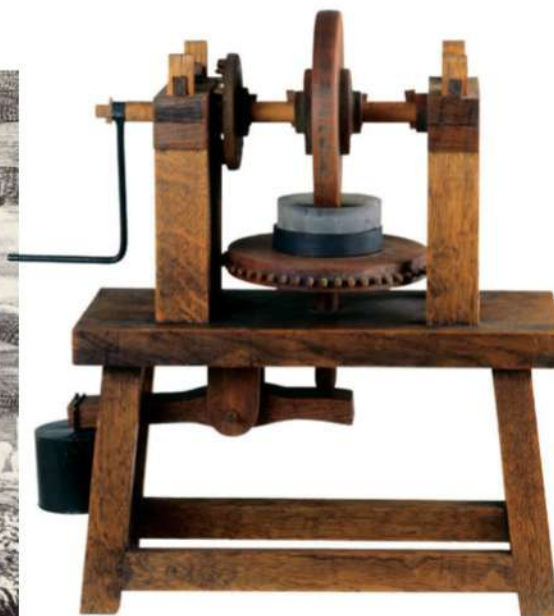


Artist's impression of Hans Lipperhey in his workshop, experimenting with lenses during his invention of the telescope. The eyepiece lens magnifies the image produced by the larger, objective lens. The lens grinding machines and lathes are powered by treadles beneath the benches.



Above: Early depiction of a 'Dutch telescope' from the 'Emblemata of zinne-werck' (Middelburg, 1624) of the poet and statesman Johan de Brune (1588-1658). The print was engraved by Adriaen van de Venne.

device. His application was denied, because of the simplicity of the invention – it was really just two lenses held at a certain distance apart in a tube. However, the officials at The Hague saw the potential of Lipperhey's instrument, and commissioned him to build three sets of double-telescopes (ie binoculars). The Dutch States General paid Lipperhey handsomely for his work: he received more than enough to buy the house



Above: Lens grinding machine, designed by Leonardo. Lipperhey used a similar machine to grind concave lenses for the eyepieces of his telescopes and a different one to make the larger, convex lens that collects the light (the objective lens).

next to his and pay to have major renovation work carried out.

The States General was probably justified in refusing Lipperhey a patent. Within a few weeks, another Dutch spectacle maker, Jacob Metius (1571-1630), submitted a very similar application. In the 1620s, yet another retrospective claim for primacy of the invention of the telescope came to light. Zacharius Janssen (1580-1638), whose house was a few doors away from Lipperhey's, may have beaten Lipperhey to it.

The earliest drawing of a telescope is a sketch in a letter by Italian scholar Giambattista della Porta (1535-1615) in 1609. Della Porta later claimed he had invented the telescope years before Lipperhey, but he died before he could provide evidence of his claim. It is likely that long before Lipperhey many lens makers had held two lenses in the right configuration and seen a slightly magnified image, but not realized its potential.

Stargazing

Any uncertainty in the story of the telescope falls away in 1609, when other people heard about the new instrument, made their own, and used it for a novel and world-changing purpose: gazing at the night sky. The first person to note that he had gazed upwards in this way was English astronomer and mathematician Thomas Harriot (1560-1621), who made a sketch of the moon as



The Hubble Space Telescope, in orbit above Earth's atmosphere. Hubble has a concave mirror, rather than an objective lens, to gather light. A camera inside takes pictures using that light, producing incredible, clear images of a wide range of astronomical objects.



Above: Compound microscope designed by English scientist Robert Hooke (1635-1703), whose 1665 book *Micrographia* revealed the microscopic world to the public for the first time. Unfortunately, Lipperhey died long before the book was published. The glass balls and lenses focused light onto the specimen.

seen through his telescope on July 26, 1609. Most famously, Galileo Galilei (1564-1542) did the same, and much more, four months later. He published his monumental findings in his book *Sidereus Nuncius* (*The Starry Messenger*) in 1610.

Hans Lipperhey is often also credited with the invention of the microscope, or to be more precise, the compound microscope (consisting of two or more lenses, rather than one). Here again, Zaccharius Janssen probably invented the device around the same time as, if not before, Lipperhey. Again, there is no patent for the microscope, because it was inevitable that, at some point, someone would arrange two lenses in the right way to make things look bigger.

“People made their own and used it for a world-changing purpose: gazing at the night sky”



Galileo Galilei (1564-1642)

Although Lipperhey was by all accounts a gifted craftsman, and was the first to submit a patent application for the telescope, Galileo is the real genius in this story. His careful and thorough observation of the moon and his discovery and observations of the moons of Jupiter were key in overturning the long-standing, dogmatic theory that the earth is at the centre of the Universe.

Galileo improved the basic telescope design, and by August 1609, had managed to make his own instrument with a magnification of 8x (8-to-1), compared to Lipperhey's instrument, which could only magnify 3x. In the 1610s, he also experimented with the compound microscope, and in the 1620s, he became one of the first to make biological observations with microscopes.

Galileo was a great thinker, and is often called the father of physics or even the father of modern science. He was much more a pure scientist than an inventor, although he did invent a primitive thermometer and a geometrical compass, and he did not actually invent the telescope.

Lipperhey's and Janssen's home city of Middelburg was famous for its spectacle makers, thanks to its supply of fine-quality, bubble-free glass and to a superior lens-grinding technique that was developed in the city. Working with high-quality glass was a novelty in Northern Europe in the 17th century the secret of its manufacture had been exported from Italy, which had had the monopoly on fine-quality glass since the 13th century.

In a sense, then, along with the lens grinders of Middelburg, the Italian glassmakers of the 13th century also deserve credit for these wonderful, world-changing inventions.



Cornelius Drebbel

(1572–October 1633)

The person who designed and built the first submarine, Dutch inventor Cornelius Drebbel, is not really a household name. But his brilliant mind, his grasp of chemical processes and the forces of nature made him one of the most prolific and best-known inventors of the 17th century.

Cornelius Drebbel was born in Alkmaar, in the Netherlands (then the Dutch Republic), the son of a wealthy farmer. He had little formal schooling, but aged 20 he was apprenticed to the Dutch painter, engraver and publisher Hendrick Goltzius (1558–1617) in Haarlem. During his apprenticeship, Drebbel had the chance to experiment with more than engraving. He learned the art of alchemy, and throughout the rest of his life, his work was dominated by the elements of that art: earth, air, fire and water.

Drebbel moved back to Alkmaar in 1598, and began creating ingenious inventions. In 1604, he demonstrated the one that would bring him fame:

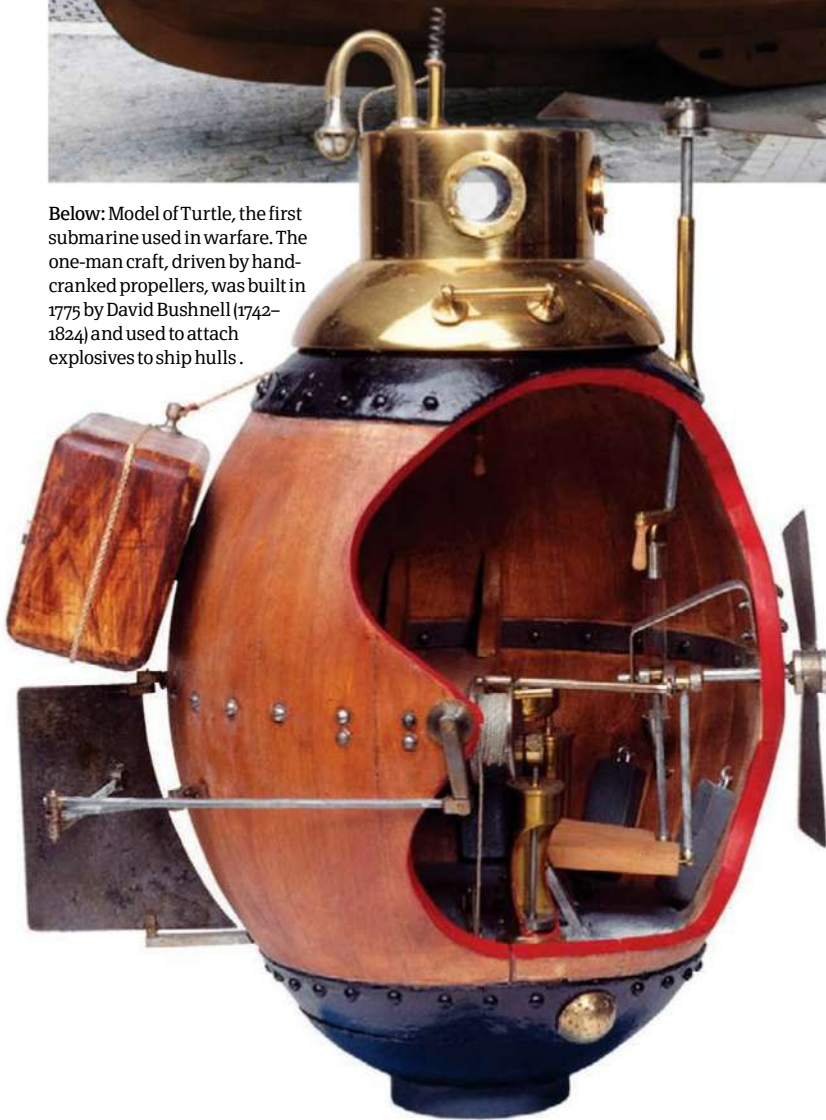






This reconstruction of one of Drebbel's submarines sits in Heron Square, London. It was based on design documents found at the Public Records Office in London, and made in 2003.

Below: Model of Turtle, the first submarine used in warfare. The one-man craft, driven by hand-cranked propellers, was built in 1775 by David Bushnell (1742–1824) and used to attach explosives to ship hulls.



a fascinating astronomical clock called the Perpetuum Mobile. In the patent for the device, Drebbel claimed it could run for decades without a visible source of power.

The Perpetuum Mobile displayed the hour, day and date, the phases of the Moon and the position of the Sun and planets. It was powered by changes in air pressure and temperature, a fact that Drebbel was aware of, although at the time he was happy for a bit of mystique to surround his invention. Later in 1604, he was called to England to show it to King James I (1566–1625), and as news spread of this remarkable clock, Drebbel gained notoriety and invitations to show his invention across Europe.

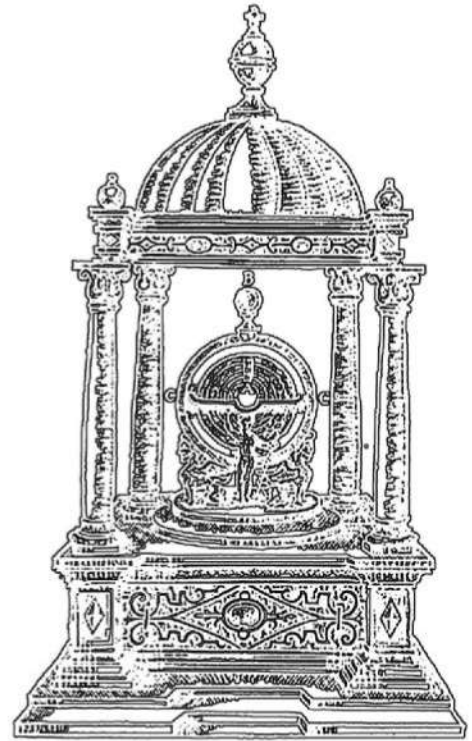
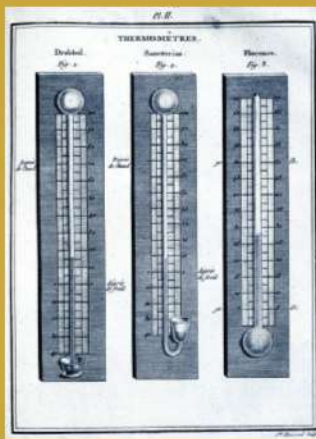
From 1604 until his death, Drebbel created and demonstrated many new and improved inventions. Among them was a process for making an intense scarlet dye, a technology that was to endure well beyond his lifetime. He also invented a thermostatically controlled furnace (the first known autonomous control system); a portable bread oven for the Dutch army; a form of air conditioning, which he reportedly demonstrated in the auspicious Westminster Hall in London; and an automatic chicken incubator. He also invented a primitive, though important, thermometer (see box).

The development of thermometers

One of Cornelius Drebbel's most important inventions was a basic thermometer. His instrument relied on the expansion and contraction of air trapped in a glass tube.

Drebbel's instrument was a thermoscope – an instrument that gives an indication of temperature while having no scale with which to measure it. At least three other experimenters produced air thermoscopes around the same time, but what set Drebbel's apart was that he used it to control his thermostatic devices. His was the one that had the most influence on scientists in the next generation.

It was Daniel Gabriel Fahrenheit (1686–1736) who invented the prototype of the modern liquid-in-glass thermometer. He also created the first accurate temperature scale, defined by fixed points – one of them was salted ice water, one was his wife's armpit. In the eighteenth and nineteenth centuries, the use of accurate thermometers contributed hugely to scientists' understanding of the behaviour of matter and to the development of the concept of energy.



Drebbel also experimented with light and lenses: he constructed an early form of projector, and one of the first practical microscopes. Both these devices were made with lenses he had ground using a machine of his own design. Drebbel's microscope was a distinct improvement on the few that already existed, and was important in the development of microscopy.

The first submarine

His most notable achievement, however, was designing, constructing and trialling the invention he is now best known for: the world's first submarine. Sadly, no convincing contemporary illustrations of Drebbel's invention exist, but there are contemporary accounts and modern best guesses of how he might have built it. Between 1620 and 1624, Drebbel built three different versions of his vessel, while working for the English Royal Navy. He tested them in the River Thames in London. Eyewitness accounts suggest that his vessels could stay submerged for hours at a time, diving as deep as 4 to 5 metres (13 to 16 feet) beneath the surface.

The submarines contained large pigskin bladders for buoyancy; these were filled with and emptied of water as necessary. Each craft was a sealed wooden double-hull craft with leather-sealed holes along the sides through which oars protruded. The third and largest vessel could



carry 16 people, 12 of them oarsmen. The hull was covered with greased leather to make it watertight. Some accounts suggest that long tubes allowed the oarsmen to breathe. However, there is also evidence that Drebbel may have used a chemical reaction – heating saltpetre (potassium nitrate) – to produce oxygen.

Drebbel tried to convince the English Royal Navy to adopt his submarine for use in warfare. Despite his relationship with the royal family, the Navy was not interested. It was 150 years before submarines were used for military purposes.

Above: Drebbel's last submarine is shown only partially submerged in the River Thames, London, in this 1626 illustration by G.H. Tweedale. Legend has it that King James even had a ride in the vessel.

Top Right: Drebbel's Perpetuum Mobile clock, from *Dialogue Philosophicall* by Thomas Tymme. The central sphere (A) represents Earth; the upper (B) lunar phases.



Benjamin Franklin

(17 January 1706–17 April 1790)

When the United States of America was born on 4 July 1776, one of the men who signed the Declaration of Independence was Benjamin Franklin. A fine statesman, Franklin was also an important figure in 18th-century science and invention – just the sort of person a new nation needs.

Benjamin Franklin was born in Boston, Massachusetts, USA. He was one of 17 children, and his parents could only afford to send him to school for two years. He was keen to learn, however, and was an avid reader – and at just 12 years old, he became an apprentice at his older brother's printing firm. Following a dispute with his brother five years later, Franklin ran away from home to make a new life in Philadelphia. Penniless to begin with, he managed to find an apprenticeship in a printer's firm there, and soon set up his own printing shop.

By the 1740s, Franklin was extremely successful – he now owned a publishing company as well as



Coloured lithograph illustrating Franklin's 1752 experiment that proved lightning is an electrical phenomenon. On the ground, beside Franklin, is a Leyden jar to collect electric charge drawn off the thundercloud through the kite string.





Empire State Building being struck by lightning. At the top is a lightning rod that helps to discharge thunderclouds over the city. As well as draining charge away, the building receives about 100 lightning strikes each year.

Researches in electricity

Franklin conceived of the lightning rod after carrying out research into electricity, a hot topic at the time. In 1747, he set up a laboratory at his own home. In the mid-1740s, scientists in Germany and Holland had invented a way of storing large amounts of electric charge, in a device called a Leyden jar (right). Franklin connected several of these jars together, so that they could produce a much stronger effect.

In five letters to Britain's Royal Society, Franklin laid down the foundations for the proper study of electrical phenomena. He was the first person to use the terms 'charge' and 'discharge', the first to write about 'positive' and 'negative' electricity, and the first to understand that electric charge is not 'created', but simply transferred from place to place.



Below: Eighteenth-century Franklin-style bifocals, with sliding adjustable arms. In a letter to his friend, English merchant George Whatley, dated 1784, Franklin wrote that he was "happy in the invention of double spectacles," although it is possible someone else had invented them before him.

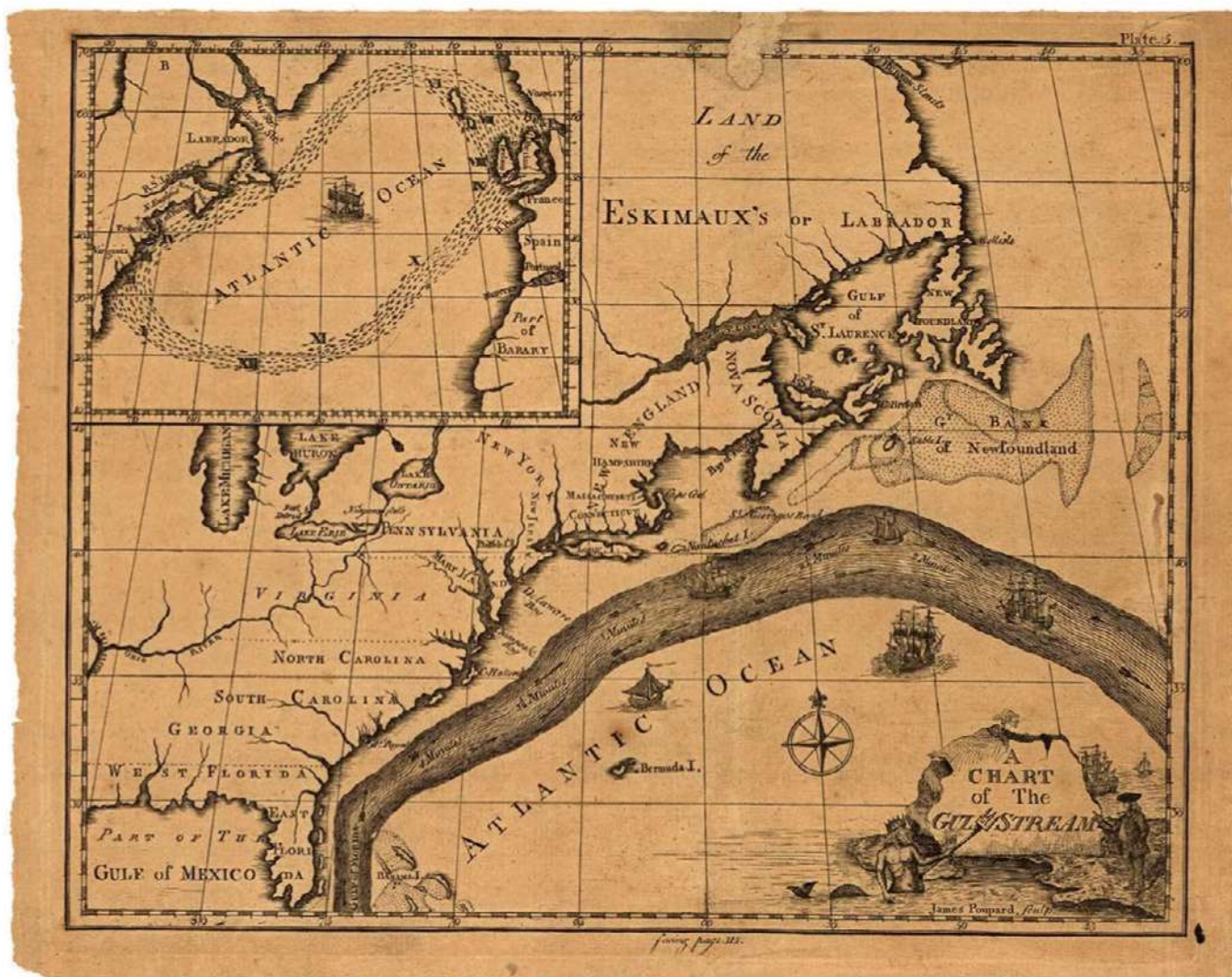
a newspaper business – and he began to spend increasing amounts of his time on scientific research. Franklin was a strong believer in the idea that science and technology could be used in order to improve society. In 1743, he founded the American Philosophical Society, the nation's first learned society. In the same year, he also invented a cleaner, more efficient way of heating the home; this was the Franklin Stove. Since he intended it to be for the public good, he didn't patent it.

In 1749, Franklin retired from business, so that he could spend more time on his research. His work on optics famously led him to invent bifocals, although others probably invented them independently, around the same time. Bifocals are like two pairs of glasses in one, in a split-lens arrangement – ideal for people who need different pairs of glasses for distance and close-up and would otherwise have to keep changing from one pair to another.

Fire prevention was a major concern, as most buildings were made of wood. In 1736, Franklin founded one of America's first volunteer fire departments. In 1752, he formed America's first fire insurance company, and came up with his most famous invention: the lightning rod, aimed at preventing the risk of fire from lightning.

Lightning rods, or lightning conductors, are pointed metal spikes connected to the earth, which draw off electric charge from clouds, dramatically reducing the risk of lightning strikes. When lightning does strike, the rods carry the electricity to the ground, bypassing the building to which they are attached. They may seem like a simple or even insignificant invention today, but at the time, Franklin's invention caused a real buzz and helped to foster the idea that basic insight into natural forces can produce important practical results.





The kite experiment

Franklin's fascination with electricity and with lightning led him to carry out his famous kite experiment, in 1752. During a storm, he flew a kite into a thundercloud and drew electric charge down the wet kite string, proving for the first time that lightning is an electrical phenomenon.

Between 1757 and 1775, Franklin spent most of his time travelling between Europe and America, negotiating between the British, the French and the Americans during the turbulent period leading up to American independence. During this period, he became the first person to carry out detailed studies of the Gulf Stream, a warm current of seawater that originates in the Gulf of Mexico and travels across the Atlantic Ocean to Europe. His resulting map of the Gulf Stream

actually helped speed travel and postal services across the ocean.

In addition to his scientific work, Franklin created America's first lending library; he founded America's first hospital (Pennsylvania, 1751) and university (The Library Company, 1731), pushed through early environmental regulations and was a vocal advocate of the abolition of slavery. He was also America's first Postmaster General, for which he was commemorated on America's first postage stamp, issued in 1847.

“Franklin was a strong believer in the idea that science and technology could improve society”

Above: Franklin's 1786 map of the Gulf Stream. Franklin did not discover the current, but he was the first to study it systematically, after noticing that mail ships took longer crossing the Atlantic from America to Europe than from Europe to America.



James Watt

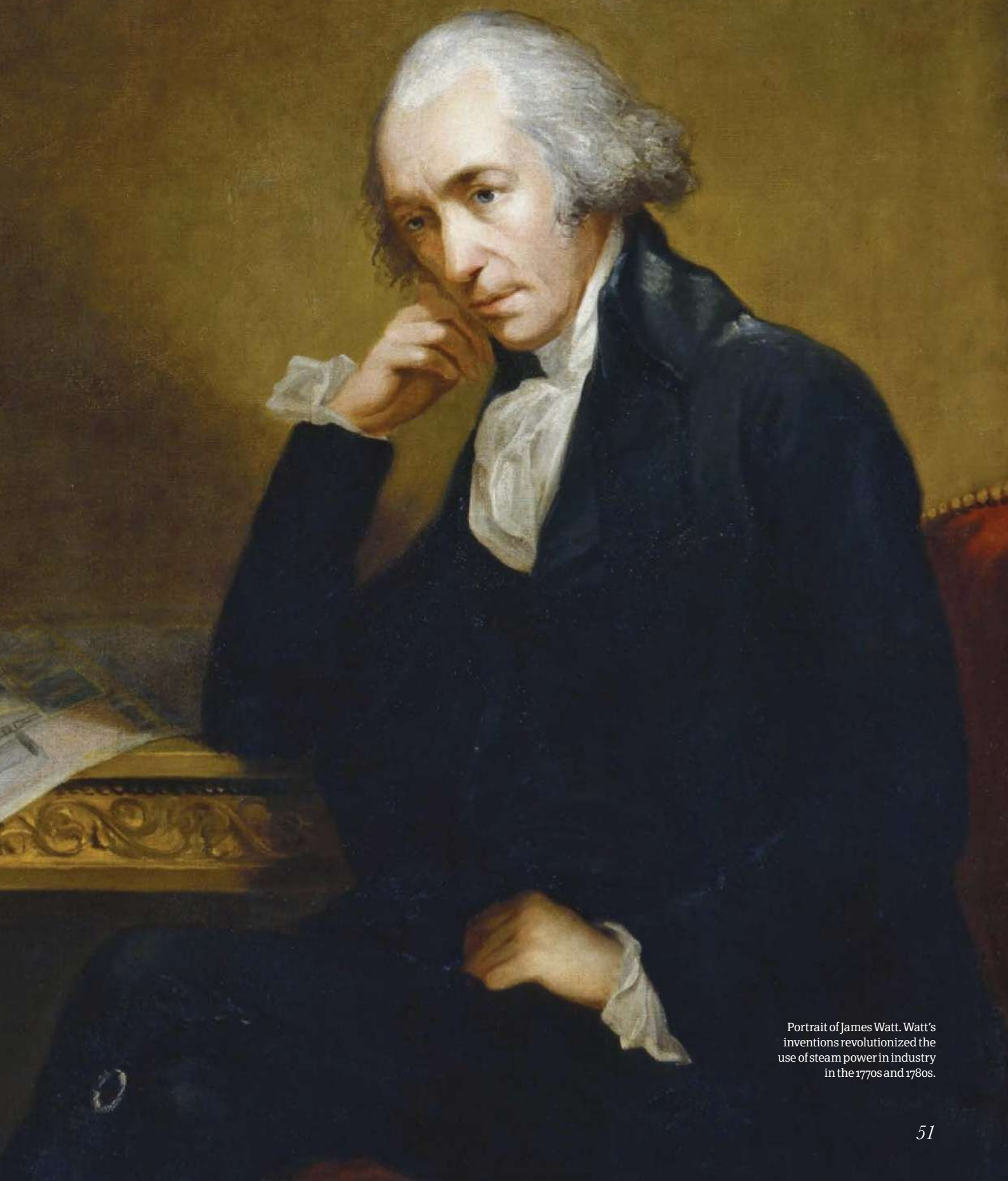
(19 January 1736–25 August 1819)

One afternoon in May 1765, Scottish engineer James Watt had an idea that changed the world. Watt had hit upon a clever device to make steam engines more efficient and more powerful. It was this device and his other inventions that made steam the driving force of the Industrial Revolution.

English engineer Thomas Newcomen (1663–1729) built the first practical steam engine in 1712 to pump water from coal mines. By the time of Watt's birth, there were nearly a hundred Newcomen engines across Britain, and several more in other countries.

Newcomen's engine relied on atmospheric pressure to push down a piston inside a huge, open-topped vertical cylinder. That could only happen if there was a vacuum inside the cylinder, beneath the piston. Newcomen achieved the necessary vacuum by condensing the steam inside the cylinder back into water, which takes up only a tiny fraction of the volume





Portrait of James Watt. Watt's inventions revolutionized the use of steam power in industry in the 1770s and 1780s.



Above: Reconstruction of Watt's Workshop at the Science Museum, London, after the contents were removed from Heathfield Hall, Handsworth, in Birmingham. Watt was using the busts on the workbench to test a machine he invented to copy sculptures – a kind of three-dimensional photocopier.

steam does. A system of valves allowed steam to fill the cylinder, then sprayed in cold water to condense the steam. Having to cool the cylinder down for each stroke of the piston, and then heat it up with steam ready for the next stroke, made the engine incredibly inefficient. It was this fact that Watt addressed that day in 1765.

Early experimenting

James Watt was born in Greenock, a town on the River Clyde, west of Glasgow in Scotland. His father was a ship's instrument builder. Using a

tool kit his father had given him, Watt became a skilled craftsman from an early age. Following a year working in Glasgow, and a year in London learning the trade of making mathematical instruments such as theodolites and compasses, Watt wanted to set up his own shop. After repairing an instrument for a professor at Glasgow University, he was offered a room there to use as a workshop, and earned a living making and selling musical instruments as well as mathematical ones.

In 1763, Watt began experimenting with a model of a Newcomen engine. He quickly realized just how much fuel, steam and heat Newcomen's design wasted. Watt's great idea of 1765 was the 'separate condenser'. In Watt's design, the steam was condensed in a chamber connected to but separate from the cylinder. The

“Watt quickly realized just how much fuel, steam and heat Newcomen's design wasted”



The lunar society

James Watt was a member of a very important society: an informal group of scientists, engineers, industrialists, philosophers, doctors, artists and poets called the Lunar Society.

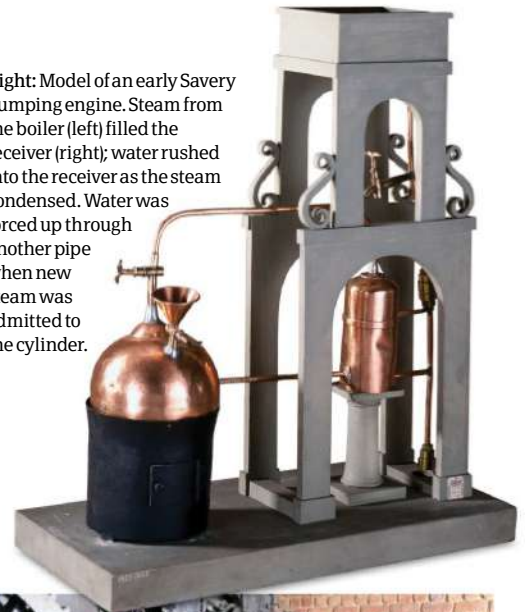
This group of intellectuals typified the spirit of the Age of Enlightenment – that period of history when people began believing that science, technology and reason could, and should, shape society. Their activities centred on regular meetings, which were often held at the house of Matthew Boulton, also a member. In addition to the meetings, the members of the group were in frequent communication by letter.

The Lunar Society was very important in the transformation of Britain from a rural, agricultural society to an urban, industrial one – it has been described as the revolutionary committee of the Industrial Revolution. The society's name was derived from the fact that the meetings were always held on the Monday closest to full moon; the moonlight made it easier for members to get home.

chamber was held at a lower temperature, so that the cylinder could remain at boiling point. Watt patented his invention in 1769. The engineer and entrepreneur Matthew Boulton (1728–1809) went into business with Watt in 1775. Their partnership lasted until Watt's retirement in 1800 and completely revolutionized the use of steam engines in industry.

Until 1782, steam engines were still used only to pump water in coal mines. That same year, on Boulton's request, Watt invented a way to make a steam engine produce a rotary motion, rather than an up-and-down motion – and the resulting 'rotative' steam engines turned out to be an immediate success. Before long, Watt's rotative engines were installed in textile mills, iron foundries, flour mills, breweries and also paper mills.

Right: Model of an early Savery pumping engine. Steam from the boiler (left) filled the receiver (right); water rushed into the receiver as the steam condensed. Water was forced up through another pipe when new steam was admitted to the cylinder.

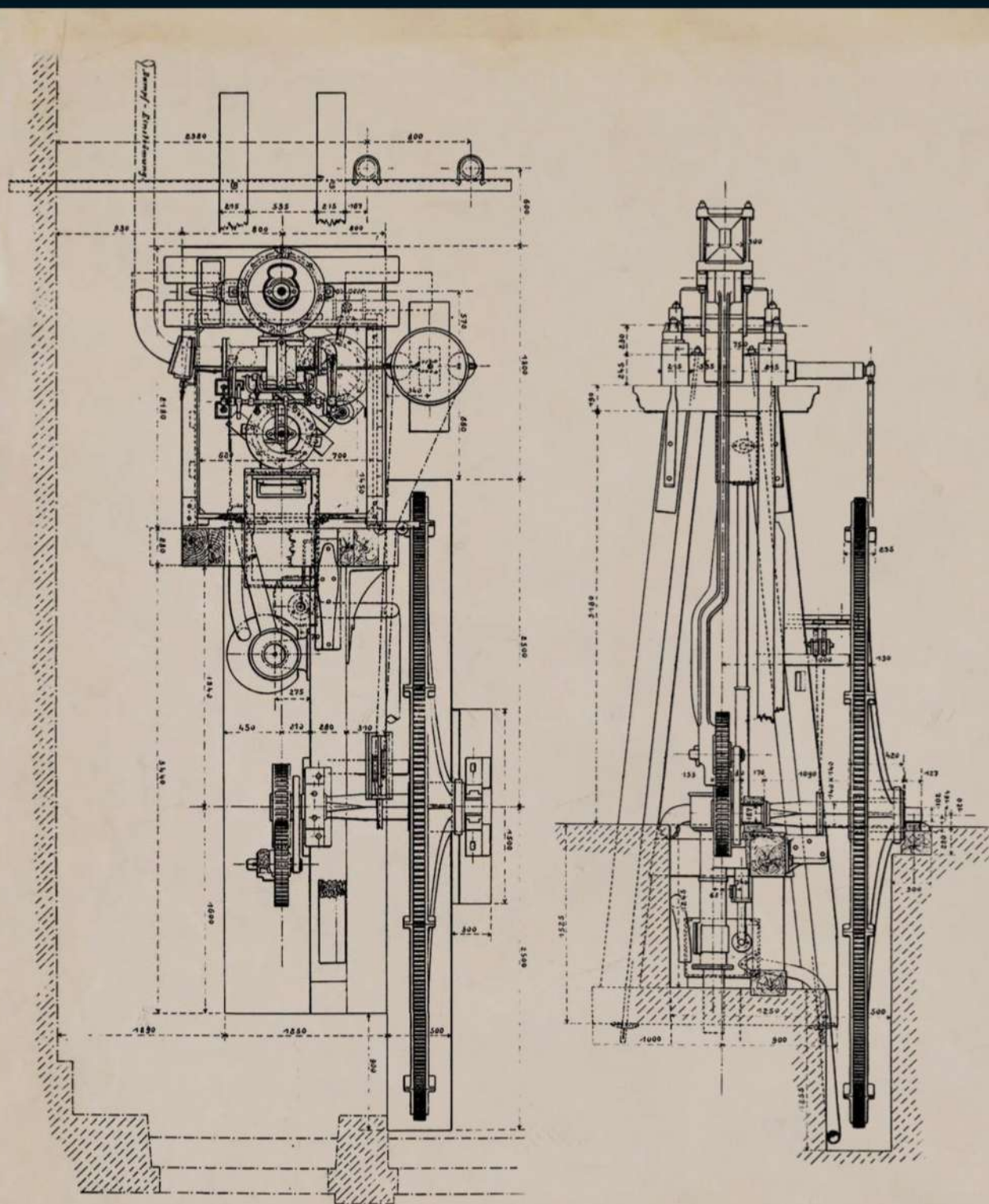


Above: Watt rotative engine at the Science Museum, London. In the background is the cylinder; to the right, the speed-regulating governor; in the foreground, the flywheel.

Watt made many other important improvements to steam power – including, in 1782, the 'double-acting' engine where steam was admitted to the cylinder alternately above and below the piston, – all choreographed by a clever system of automatic valves. He also invented a steam-pressure gauge and a way of measuring the efficiency of a steam engine. In 1788, he invented the 'governor', a device that automatically regulated the speed of an engine.

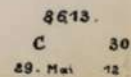
Watt was also a respected civil engineer, working mostly on canal projects. He is credited with other inventions too, including a popular device for making multiple copies of letters. However, steam was his life's work. In honour of his achievements in steam power, the international unit of power, the 'watt', is named after him.

Right: Top, side and end elevations of Watt's 'Lap' engine, 1788. This engine drove lapping (metal-polishing) machines that were previously driven by horses, so when Watt calculated what the machine was capable of, he devised the term 'horsepower'.



Erste Watt'sche Dampfmaschine. M.-1:20.

Disposition für die Aufstellung der



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Nicéphore Niépce

(7 March 1765–5 July 1833)

Less than 200 years ago, there was practically no way of producing a lasting image of a scene other than by drawing or painting it. Photography, invented by French scientist Nicéphore Niépce, has had a profound effect on art, education, history and science.

Nicéphore Niépce was born in Chalon-sur-Saône, France. His father was a steward to a duke, but little else is known of his childhood. When he was 21, he left home to study at a Catholic oratory school in Angers, where he became interested in physics and chemistry. His first name was originally Joseph; he began using the name Nicéphore, which means 'victory-bearer', when he joined the fight against the monarchy in the French Revolution in 1788.

It was in 1793 that Niépce first had the idea of producing permanent images. Around the same time, he and his brother, Claude (1763-1828), conceived of a new type of engine that would use explosions inside a cylinder to drive a piston.



Portrait of Niépce.
Ironically, there are no
photographs of the
inventor of photography.



Louis Daguerre (1787–1851)

After his initial successes with bitumen on pewter plates, Niépce found a way to give better definition to his photographs, or ‘heliographs’ as he called them. He used iodine vapour to make the pewter darken. In 1829, Niépce began collaborating with a French artist, Louis Daguerre. Niépce died in 1833, but by 1837, Daguerre was producing images that only needed a few minutes’ exposure. He used copper plates coated with silver iodide, which were ‘developed’ after exposure to mercury vapour and then ‘fixed’ using a strong salt solution.

Daguerre had improved the process so much that he felt justified in calling his photographs daguerreotypes. In 1839, the French Government gave Daguerre’s process away, patent-free, as a ‘gift to the world’, and paid Daguerre and Niépce’s son a handsome pension. Daguerreotypes became very fashionable, dominating early photography and spurring the development of subsequent photographic technologies.

Together, they invented the world’s first internal combustion engine, the *Pyréolophore*. Its fuel was a highly flammable powder of spores from a fungus called *lycopodium* (which, quite coincidentally, was later used in photographic flash bulbs). They received a patent in 1807, and two years later the brothers entered a government competition to design a replacement for a huge pumping machine on the River Seine in Paris. Their ingenious idea was highly favoured by the judging committee, but in the end the pumping machine was never replaced.

Shortly after its invention in 1796, Niépce learned about a new method of printing illustrations, called lithography, which allowed artists to draw their design directly onto a



“He tried to project an image onto a printing plate, hoping to find a way to make it permanent”

printing plate, rather than having to etch it into wood or metal. Niépce couldn’t draw, so he decided to try and project an image onto the plate instead, hoping to find a way to make the image permanent. To project the image, he turned to an existing technology called the ‘camera obscura’. Popular with Renaissance artists who wanted to produce an accurate representation of a scene, the camera obscura – literally ‘darkened chamber’ – is a simple closed box or room in which a lens casts an image on a screen.

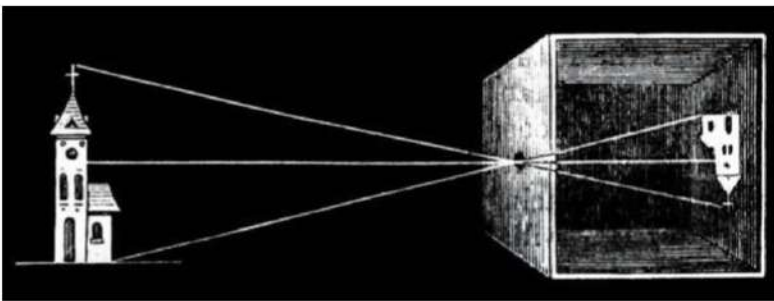
Picture taking

Niépce had some success with paper coated with light-sensitive compounds of silver. Images did register on the paper, but they completely

Above: *The Ladder*, photographed c.1845 by William Fox Talbot (1800–1877). Talbot invented the calotype process, which involves making prints from negatives.



Table Servie (Set Table) by Niépce. Some experts believe this to be the oldest photograph, dating it to 1822, but it is more likely to be from c.1832. The original was on a glass slide, now broken.



Above: Diagram showing how a pinhole camera obscura works. Making the hole bigger lets more light in, producing a brighter image, but the image becomes blurred. A lens brings it back into focus, and two lenses can bring the image right way up.



Above: An 1825 copy of an earlier print. Niépce soaked the print in varnish in order to make it translucent, then laid it on a copper plate coated with his bitumen solution. After washing the plate in acid, he was left with an etching, from which to make this print.

blackened when they were exposed to light as they were removed from the camera. Also, this process produced negatives: the parts of the paper where the most light fell became the darkest parts of the resulting image. So Niépce tried using compounds that bleach in sunlight, instead of those that darken. In 1822, Niépce turned to a substance called bitumen of Judea, a thick, tarry substance that hardens and bleaches when exposed to light. His first real successes were in producing permanently etched metal plates. For this, he placed drawings on top of a sheet of glass, which in turn lay on the metal plate coated with bitumen. After exposure to light, for days at a time, he washed away the unhardened bitumen, then treated the plate with nitric acid. The acid

etched into the metal wherever the bitumen was not present, leaving a plate from which he could make prints.

Three years later, Niépce began taking pictures of scenes, rather than 'photocopying' drawings. He dissolved bitumen in lavender oil and applied the mixture to pewter plates. Then he exposed the plates for several hours in his camera obscura. The bitumen bleached and hardened where light fell, while the unexposed bitumen – representing the darkest parts of the image – was washed away to reveal the dark metal below. These photos were not negative but positive images. The oldest photo still in existence is *View from the Window at le Gras* (1826), an eerie image of outbuildings taken from the first floor of Niépce's house.



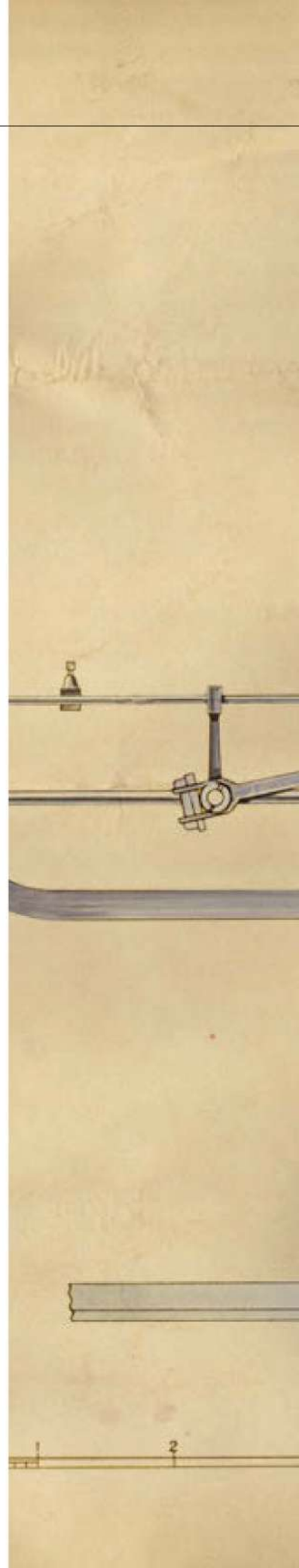
Richard Trevithick

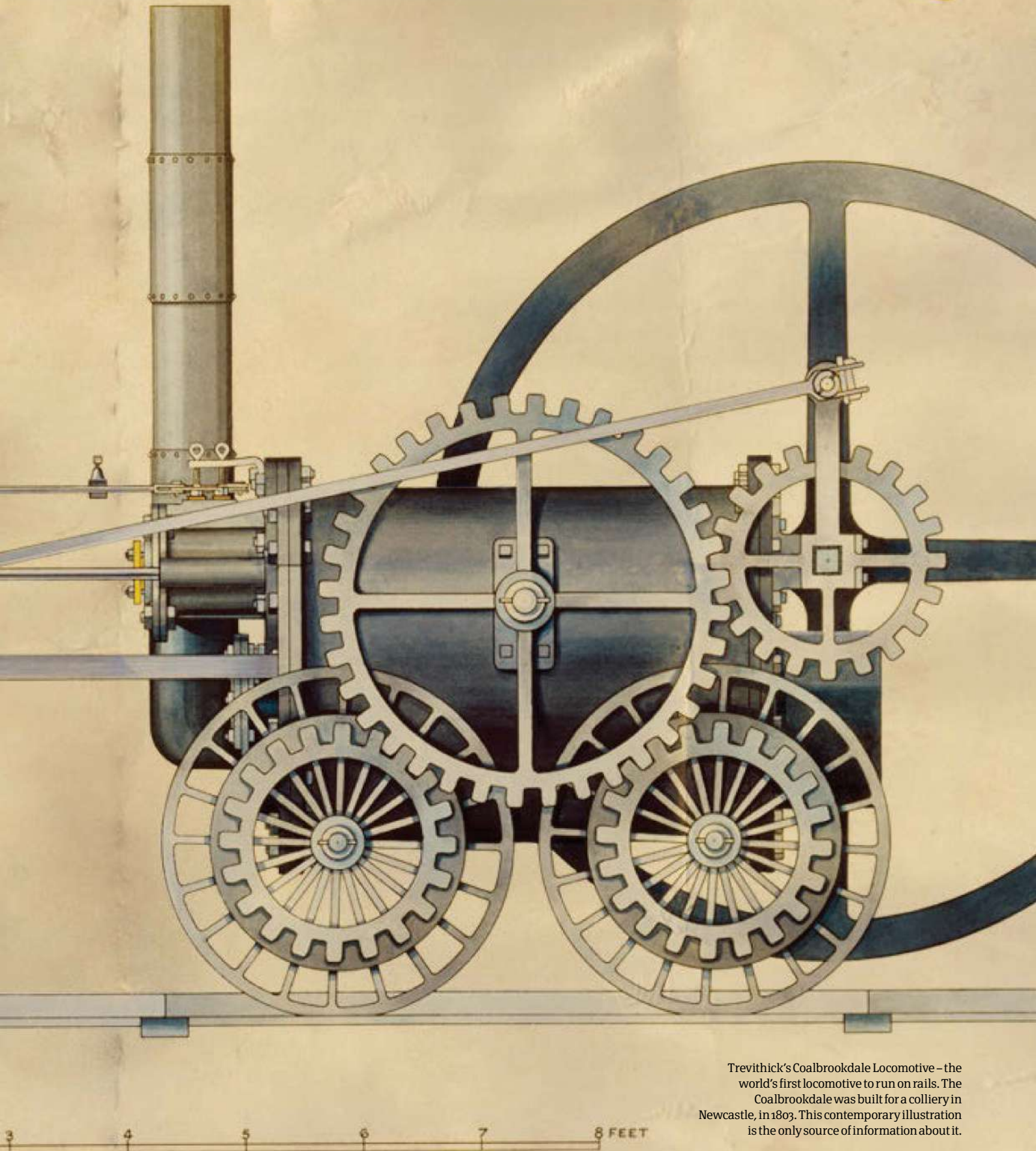
(13 April 1771–22 April 1833)

During the 19th century, the railways revolutionized travel and communication for millions of people. The coming of the railways was made possible by the invention of high-pressure steam engines by English engineer Richard Trevithick, who also designed and built the first steam locomotives.

Richard Trevithick was born in the parish of Illogan in Cornwall, England. His father was the manager of several local mines, and Richard spent much of his early life gaining practical knowledge of steam engines. He did not do well at school, but he earned an excellent reputation after he became a mine engineer, aged 19.

At that time, working engines used steam only at atmospheric pressure or slightly above. Trevithick realized early on that steam under high pressure could lead to more compact, more powerful engines. Most people at the time, including steam pioneer James Watt (1736–1819, see page 50), feared 'strong steam', believing that





Trevithick's Coalbrookdale Locomotive – the world's first locomotive to run on rails. The Coalbrookdale was built for a colliery in Newcastle, in 1803. This contemporary illustration is the only source of information about it.



Above: An artist's impression of Trevithick's London Steam Carriage of 1803, which was the world's first reliable self-propelled passenger-carrying vehicle. It had a top speed of about 15 kilometres per hour (9 miles per hour) on the flat, and weighed about a tonne when fully laden.

the risks of explosion were too high. Trevithick began experimenting with high-pressure steam in the 1790s, and by 1794, he had built his first boiler designed to withstand high pressures, from heavy cast iron.

In 1797, Trevithick built a model steam carriage – and by 1801, he had built a full-size one, nicknamed the 'Puffing Devil', which ran successfully in Camborne, Cornwall. However, the Puffing Devil was destroyed in an accident so, in 1802, Trevithick designed a locomotive that would run on rails. At the time, rails were used with horse-drawn wagons, mainly in order to transport coal from mines to ports for onward shipping. Trevithick's locomotive, built by the celebrated Coalbrookdale Ironworks, was possibly the first locomotive to run on rails. However, little is known about the locomotive, and only a single letter and drawing relating to it survive.



Above: Trevithick's demonstration of the potential of steam trains in Euston, London, in 1808 – later called 'The Steam Circus'. The locomotive was called *Catch-Me-Who-Can*, because – to show that travel by steam would be faster – Trevithick raced it in a 24-hour race against horses, and won.

In 1803, Trevithick built another road vehicle, which he demonstrated in London. It attracted a lot of attention, but it was more expensive, noisier and more inconvenient than horse-drawn carriages, and went no further. In the same year, one of Trevithick's boilers exploded in Greenwich, London. This event could have set back his work; instead Trevithick invented a safety device, a 'fusible plug', that he publicized but did not patent, in order to promote high-pressure steam.

Steam trains

The world's first steam train – carriages pulled by a locomotive – was the result of a bet. The owner of the Pen-y-Darren ironworks in Merthyr Tydfil, Wales, bet the manager of a neighbouring ironworks that a steam locomotive could be used to pull carriages filled with iron from his premises to a canal 16 kilometres (9 miles) away. The

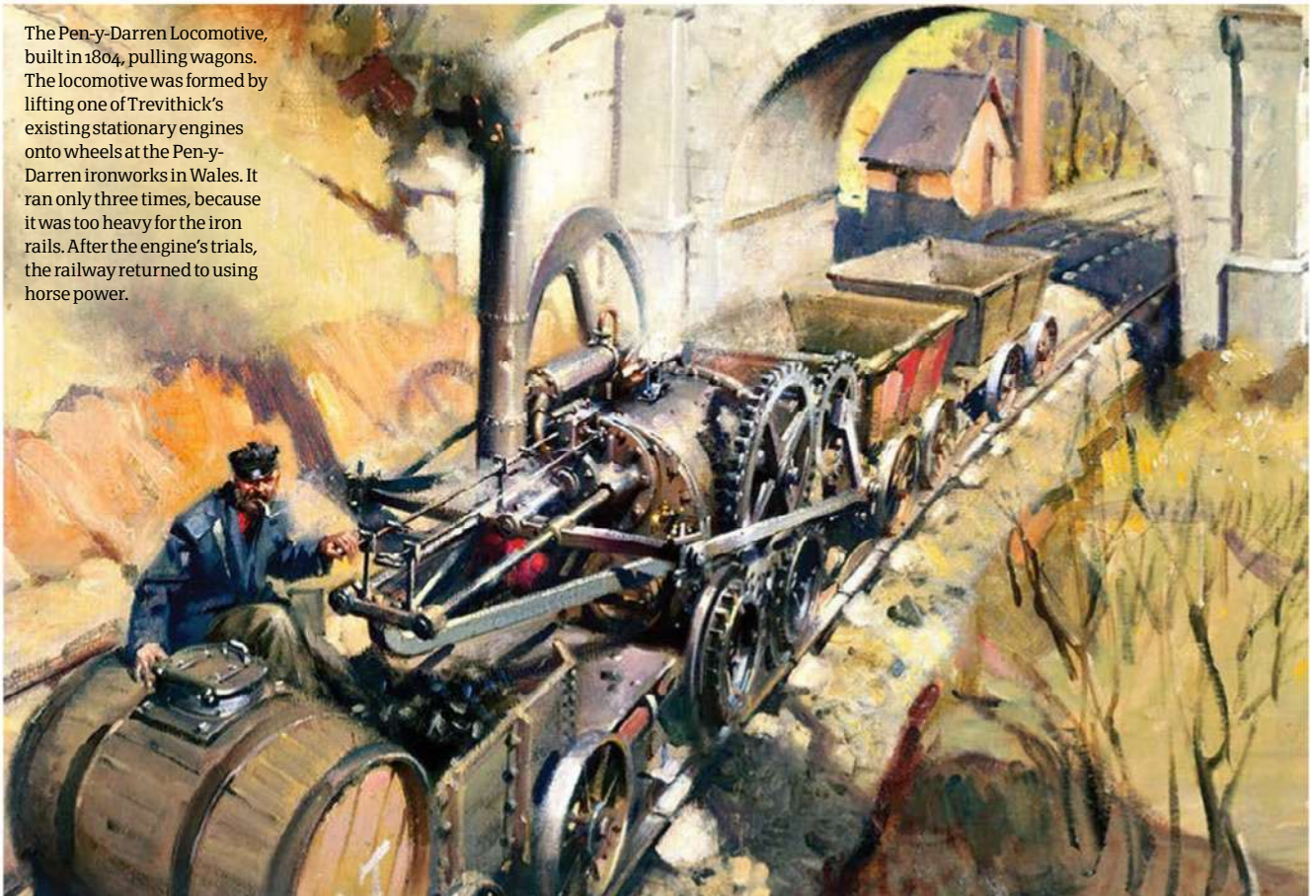
The rainhill trials

Although Richard Trevithick laid the foundations of the railways, it was not until the 1820s that people began to see steam trains as a serious alternative to horse-drawn transport. The first public railway designed from the start to use steam power was opened between Stockton and Darlington, in northern England, in 1825. Two of the shareholders and engineers on that first railway were father and son George (1781–1848) and Robert Stephenson (1803–1859).

In 1829, the Stephensons entered into the Rainhill Trials, a competition to find a locomotive for the forthcoming Liverpool and Manchester Railway. Their entry was called Rocket, and its many innovations made it the blueprint for all future steam locomotives. Rocket was the only locomotive to complete the ten 5-kilometre (3-mile) round trips required in the competition. When empty of cargo and passengers, it ran at a maximum speed of 47 kilometres per hour (29 miles per hour).



The Pen-y-Darren Locomotive, built in 1804, pulling wagons. The locomotive was formed by lifting one of Trevithick's existing stationary engines onto wheels at the Pen-y-Darren ironworks in Wales. It ran only three times, because it was too heavy for the iron rails. After the engine's trials, the railway returned to using horse power.



“He built a circular track in Euston, London, to promote the idea of steam trains. It was the world’s first fare-paying passenger railway”

carriages were normally pulled by horses, so the rails already existed. Trevithick built a locomotive, and in February 1804, it successfully pulled 10.2 tonnes (10 tons) of iron and about 70 people the full distance. Although the rails broke in several places under the weight, the concept of steam trains was proven. A year later, Trevithick built a lighter locomotive for a colliery in Newcastle, but although it worked, it was not put into service.

In 1808, Trevithick built a circular track in Euston, London, to promote the idea of steam trains. This was the world’s first fare-paying passenger railway. From July to September that year, Trevithick’s locomotive, the *Catch-Me-Who-Can*, ran around its track carrying passengers

who paid five shillings for the privilege (later reduced to two shillings). It pulled a single carriage at speeds of about 20 kilometres per hour (12 miles per hour).

Trevithick also built a steam-powered dredging machine; he powered a barge using one of his engines; and in 1812, he even built an engine to thresh corn. In addition to this, he invented an early propeller for steamboats and a device for heating homes, and he worked as an engineer on a tunnel under the River Thames in London, as well as on various projects in the silver mines of South America. However, it is his pioneering contributions to the birth of the railways for which Richard Trevithick will be remembered.

Below: Trevithick built the first ‘flue boiler’, in which hot exhaust gases pass through tubes inside the water tank and out through the chimney. The high-pressure steam produced made possible more compact engines.





Michael Faraday

(22 September 1791–25 August 1867)

Electric motors, generators and transformers have helped to define the modern world. English chemist and physicist Michael Faraday made the first examples of each of these devices. More pure scientist than inventor, Faraday nevertheless had a practical bent, which led him to find innovative ways of using some of the incredible things he created in his laboratory.

Michael Faraday was born in Newington Butts, in London. Unlike most scientists of his day, he was not born into a wealthy family and did not benefit from much formal education. At the age of 13, his family secured an apprenticeship for him as a bookbinder.

Faraday took the opportunity to read many of the books he bound, and from these he developed an interest in science. In 1812, he was given tickets to a lecture by English chemist Humphrey Davy (1778–1829), who was about to retire from the Royal Institution in London. Keen to move out of



Portrait of
Faraday in his
late thirties.

James Clerk Maxwell (1831–1879)

During his researches with magnetism and electromagnetism, Michael Faraday became the first to describe 'fields' of force. Several of his contemporaries expressed his discoveries in the precise language of mathematics, which Faraday's lack of formal education prevented him from doing. Most notable among these mathematical physicists was Scottish mathematician James Clerk Maxwell.

In the 1850s, Maxwell derived four equations that comprehensively describe the behaviour and interaction of electricity and magnetism. In 1864, Maxwell combined the equations, and the result was a single equation that describes wave motion. The speed of the wave described by the equation worked out to be exactly what experimenters had found the speed of light to be. Maxwell had shown that light is an electromagnetic wave. He went on to predict that light is a small part of a whole spectrum of electromagnetic radiation, a prediction that was confirmed in 1887 by the discovery of radio waves by German physicist Heinrich Hertz (1857–1894).



bookbinding, Faraday wrote up his notes from the lecture, bound them and presented them to Davy in the hope of being offered a job. Then, when a position became available, Davy employed Faraday as his assistant.

Other scientists

After Davy's retirement, Faraday travelled across Europe with him, meeting some of the most important scientists of the day. On his return, Faraday experimented in the field of chemistry, making several discoveries and inventing the earliest version of the Bunsen burner. A chance discovery in 1819/20 by Danish experimenter Hans Christian Ørsted (1777–1851) was to take Faraday in a new direction. Ørsted had discovered that whenever electric current flows, it produces magnetic forces. In 1821, Davy and his colleague William Wollaston (1766–1828) tried to use this

“Faraday succeeded where Davy and Wollaston had failed”

Michael Faraday lecturing at the Royal Institution. In 1825, Faraday instigated two series of public lectures that are still a feature of the institution: a series of Friday evening discourses and the annual Christmas Lectures, aimed at young people.



phenomenon to make an electric motor, but they could not get it to work.

Later in 1821, Faraday succeeded where Davy and Wollaston had failed. He suspended a wire over a magnet in a cup of mercury. The wire rotated around the magnet whenever electric current flowed through it, because of the interaction between the magnetic field produced by the wire and the magnetic field of the magnet. Crude though it was, this was the precursor of all electric motors, which today are found in washing machines, drills and a host of other machines and appliances. When Faraday published his results, he failed to credit Davy, and the resulting fuss caused Faraday to stop working on electromagnetism until after Davy's death in 1829.

In 1831 in the basement of the Royal Institution, Faraday made a series of groundbreaking discoveries with batteries and wires. First, he



discovered that a magnetic field produced by electric current in one wire can create, or 'induce', electric current in another wire nearby. Faraday wound two long insulated wires around a circular iron ring, which intensified the effect; what he had made was the world's first transformer. Today, transformers are a vital part of the electricity distribution network, and they are also found in many home appliances, including mobile-phone chargers and televisions.

A month later, Faraday fixed a copper disc between the poles of a strong magnet and attached wires to the disc, one via the axle and one via a sliding contact. When he rotated the disc, an electric current was produced in the wires. This was the world's first electric generator. A year later, French instrument maker Hippolyte Pixii (1808–1835) read about Faraday's discovery and made an improved generator using coils of

wire spinning close to a magnet's poles. Today, generators that supply huge amounts of electric power from power stations and wind turbines can trace their lineage directly back to Pixii's design.

In addition to his research and his inventions, Faraday instigated regular Friday discourses and the celebrated Christmas lectures at the Royal Institution; he himself was an inspiring lecturer. Later in his career, Faraday campaigned to clean up air and river pollution, and he was called upon to improve lighthouse technology and to investigate mining disasters. The most important contributions Faraday made, however, were those he made in the basement of the Royal Institution.



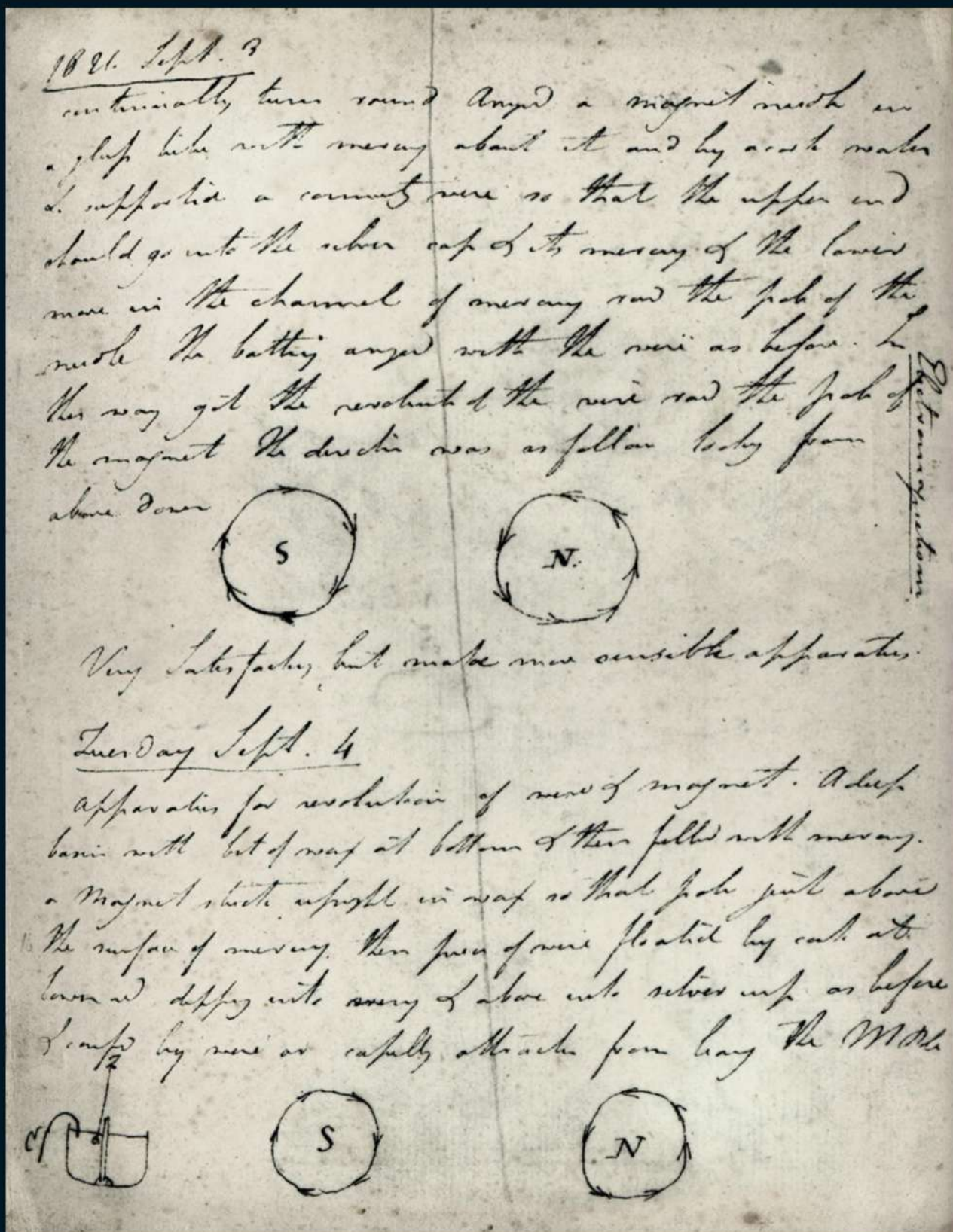
Left: Replica of the apparatus used by Faraday in 1831 that changes movement energy into electrical energy.

Below: Faraday's Giant Electromagnet (1830), under the table in a mock-up of his lab at the Royal Institution, London. Faraday discovered materials like water and wood are repelled weakly by a strong magnet – a property called 'diamagnetism'.



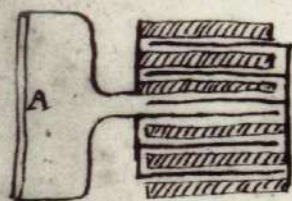
Above: Replica of Faraday's induction ring – the world's first transformer, consisting of two long wires coiled around an iron ring. A changing electric current flowing in one coil produces a changing magnetic field in the iron ring, which induces a voltage in the other coil.

Right: Pages from Faraday's laboratory notebook, September 1821, describing the world's first electric motor. Faraday describes how he suspended a wire in a basin of mercury. The wire rotated continuously around a magnet in the mercury whenever current flowed through it.



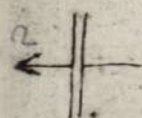
1821. Sept 3rd 1821.

Electromagnetic effects with Hans
Calverley's. To be remembered that this is a single wire? ^{Wires}

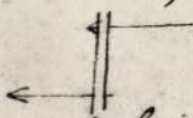


Position of the efft wire A

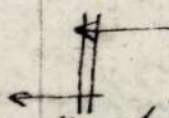
Positions at first ascertained were as follows



stray attraction



repulsion



attraction

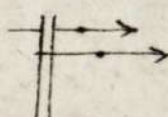


repulsion

on examining these more minutely, found that each
pole had its position of attraction & of repulsion
thus



attracted



repelled

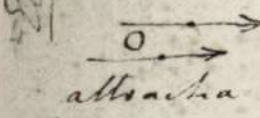


attracted

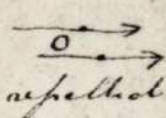


repelled

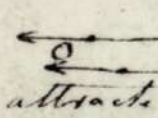
as looking from above down on to sections of the wire



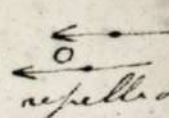
attracted



repelled

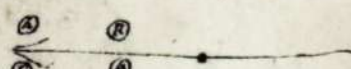
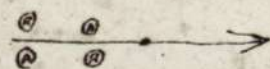


attracted



repelled

or



then indicate positions in circles round each pole
thus

1891 Sept 3



Electromagnetic

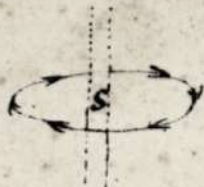
Then the wire moves in opposite arcs and each pole & the poles move in opposite arcs round the wire. I established the motion of the wire connecting ^{been} was placed upright in a cork on water in a basin and dipped into a little basin of mercury in the water and its upper end into a little ^{small} ^{cup} ^{containing} a globule of mercury. The arrangement of ^{the} poles always as at first Magnets of different power kept perpendicular to the wire did not make it revolve as Dr. Wallaston in effect but thrust it from side to side.

The wire then bent into a crank form thus and by repeated applications of the poles of the magnets the following motions were ascertained. Look from above down on the circle described by the bent part of the wire different Magnetic poles shown by letters. North pole in centre

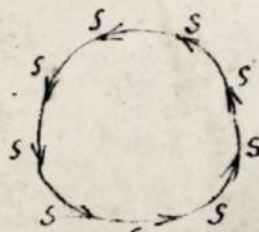


The rod in the circle is merely just there to show the front of back part

1821. Sept 3.



Magnetic poles on the outside of the wire the wire described.



Electromagnetic

The effect of the wire is always to push off at a right angle from the pole intended to go in a wire round it so when either pole was brought up to the wire perpendicular to it & to the radius of the wire it described there was neither attraction nor repulsion but the moment the pole came round in the right manner either in or out the wire moved one way or the other.

The poles of the magnet act on the bent wire in all positions and not in the direction only of any axis of the magnet so that the current can hardly be cylindrical or arranged round the axis of a body?

From the manner above a single magnet pole in the centre of one of the circles should make the wire



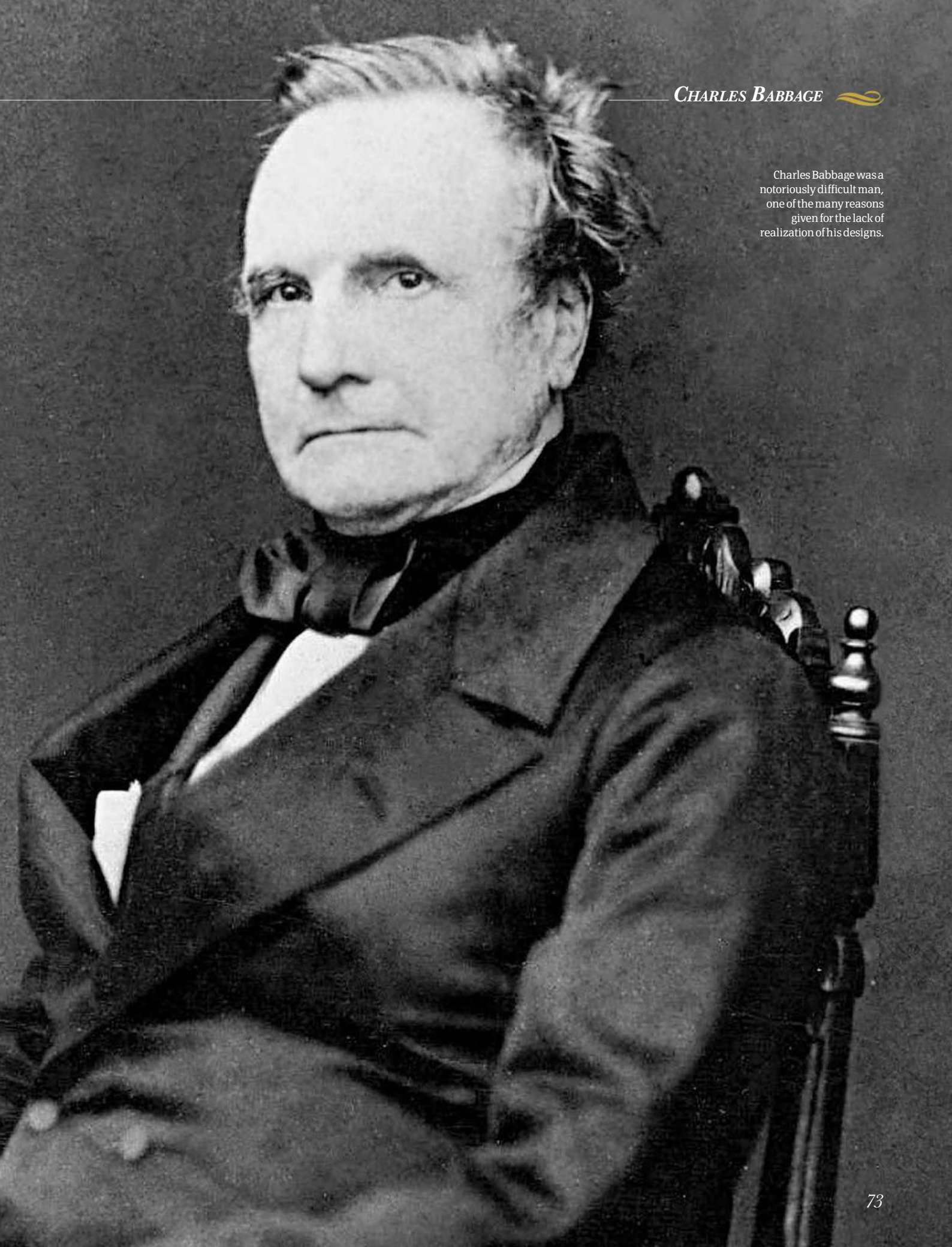
Charles Babbage

(26 December 1791–18 October 1871)

Long before the invention of the modern computer, a determined genius named Charles Babbage designed machines that would carry out complicated mathematical operations, and invented the world's first programmable computing device. Babbage was a brilliant mathematician, but he also contributed to the development of business efficiency and railway travel.

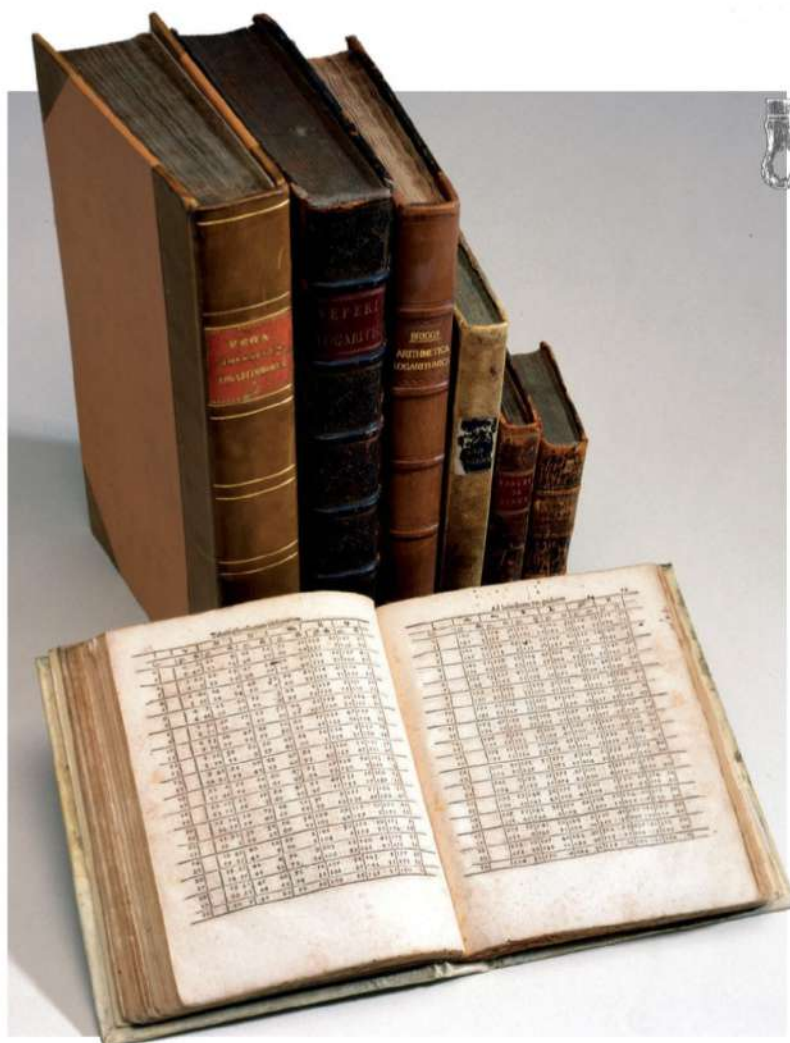
As a child, Babbage was extremely inquisitive. In his autobiography, he wrote that whenever he had a new toy, he would ask his mother "What's inside it?" and broke things open to find out how they worked. This curiosity gave him an early understanding of machines and mechanisms.

In 1810, he went to study mathematics at Trinity College, Cambridge University. At the time, mathematicians and engineers completely relied on books filled with tables of numbers in order to carry out calculations. There were tables of trigonometric functions (sine, cosine and tangent)



CHARLES *BABBAGE* 

Charles Babbage was a notoriously difficult man, one of the many reasons given for the lack of realization of his designs.

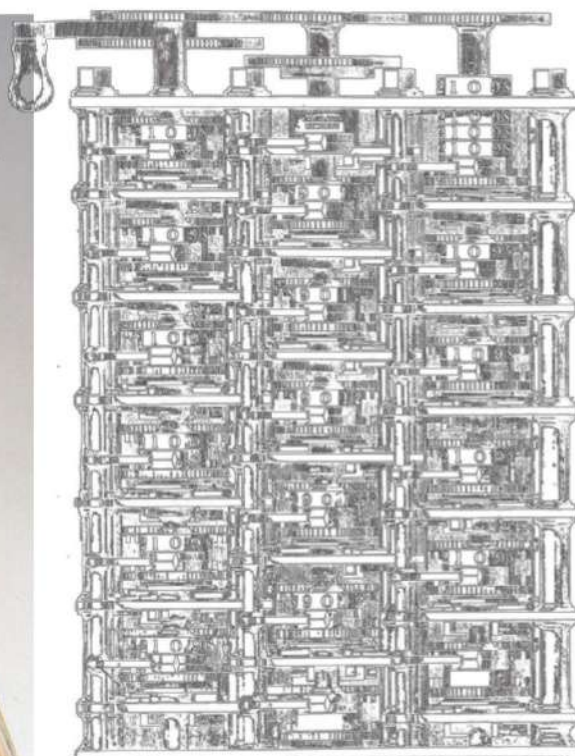


and tables of logarithms. The books contained hundreds of tables, and each table contained thousands of numbers. The values in the tables were worked out by hand, by 'computers' – a word that then meant 'people who compute'. In 1812, Babbage moved college, to Peterhouse. In the library there, he realized that there were large numbers of mistakes in the numerical tables, and that these mistakes were down to human error. At the time, various mechanical calculating machines existed, but they were limited in what they could do. As such, Babbage envisaged a machine that would be able to calculate these tables at speed as well as remove the risk of human error.

“He envisaged a machine that would calculate tables at speed and remove the risk of human error”

Above: Babbage's collection of mathematical tables. His engines were designed to make these redundant.

Top right: Babbage's Difference Engine No.1. It was built in 1832 by Joseph Clement, a skilled toolmaker and draughtsman. It was a decimal digital machine; the value of a number represented by the positions of toothed wheels marked with decimal numbers.



In 1822, Babbage presented to the Royal Astronomical Society a proposal to build a calculating machine. The society granted Babbage money to set about making his machine, and he hired an engineer to oversee the job. In a workshop close to Babbage's house, with machine tools painstakingly designed by Babbage himself, the engineer set to work. It was an enormous task, and Babbage repeatedly asked for, and was granted, more money from the British Government.

The Difference Engine

Babbage called his proposed device the Difference Engine. It was never finished, because of a dispute between Babbage and the engineer – and perhaps also because it was so complicated. The Government officially abandoned the project in 1842. Babbage later improved his design, which he called Difference Engine 2. In 1991, London's Science Museum followed Babbage's design and constructed it; in 2005, they added a printer that had also been part of Babbage's original design. Both machines worked perfectly.

In 1827, his father, his wife and one of his sons died, and Babbage stopped work and took time to travel in Europe. While he was travelling, he

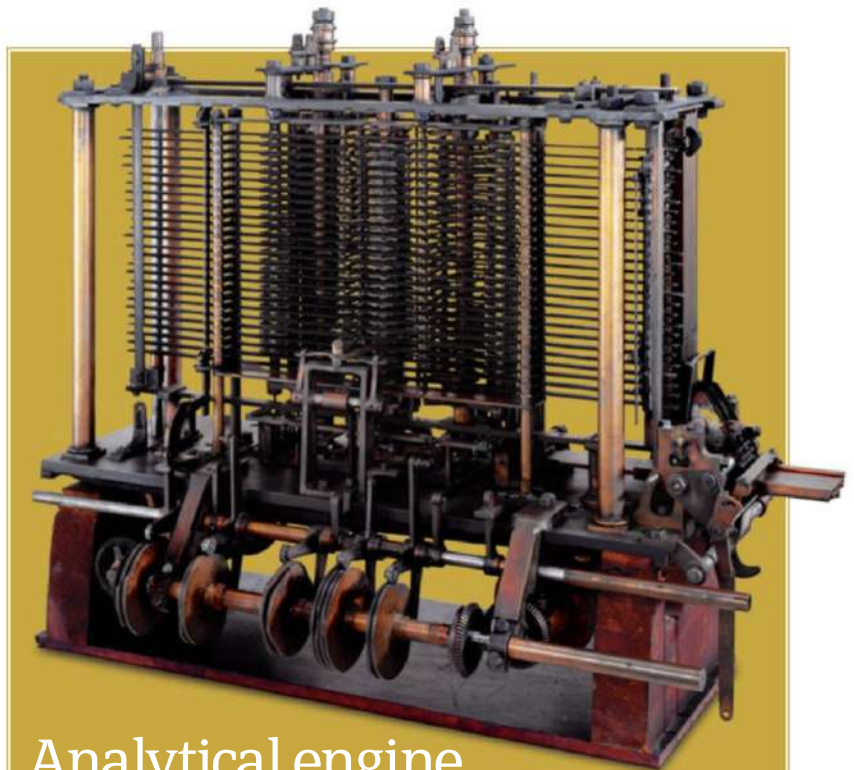


Above: Babbage's cowcatcher in use on a steam locomotive in Pakistan's North-West Frontier Province. The concept was used on trains around the world.

dreamed up a more general calculating machine, which would be able to follow sets of instructions. Babbage envisaged a machine that would have input via punched cards, would be able to store answers, and would have a printer that would output the results. By 1835, he had produced the first of many designs for an 'Analytical Engine' – the forerunner to the modern programmable computer. His design was expressed in 500 large engineering drawings, a thousand pages of engineering calculations and thousands of pages of sketches. Unfortunately, this machine was also never finished.

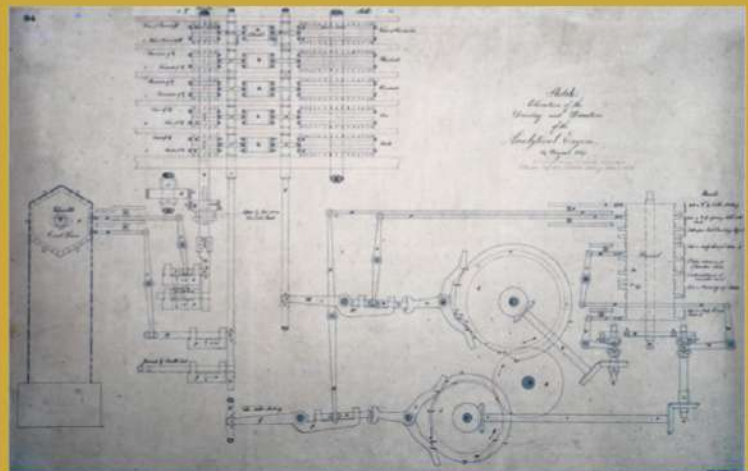
Babbage's designs inspired the pioneers of the modern computer, and this is what he is remembered for, but he also had a significant influence on other fields. While he was travelling in Europe in the 1820s, Babbage toured factories and studied the manufacturing process. In 1832, he published a book called *On the Economy of Machinery and Manufacture*, which was the beginning of studies into the efficiency of business and industry – what is now called operational research. He applied his methods to mail in Britain, and the result was the world's first cheap and efficient national postal system.

He also studied the efficiency of the railways, which were in their infancy then. He invented a special carriage filled with equipment that would record the bumps in the tracks during a journey, and a device to move objects off the track ahead of a train – affectionately called a cowcatcher.



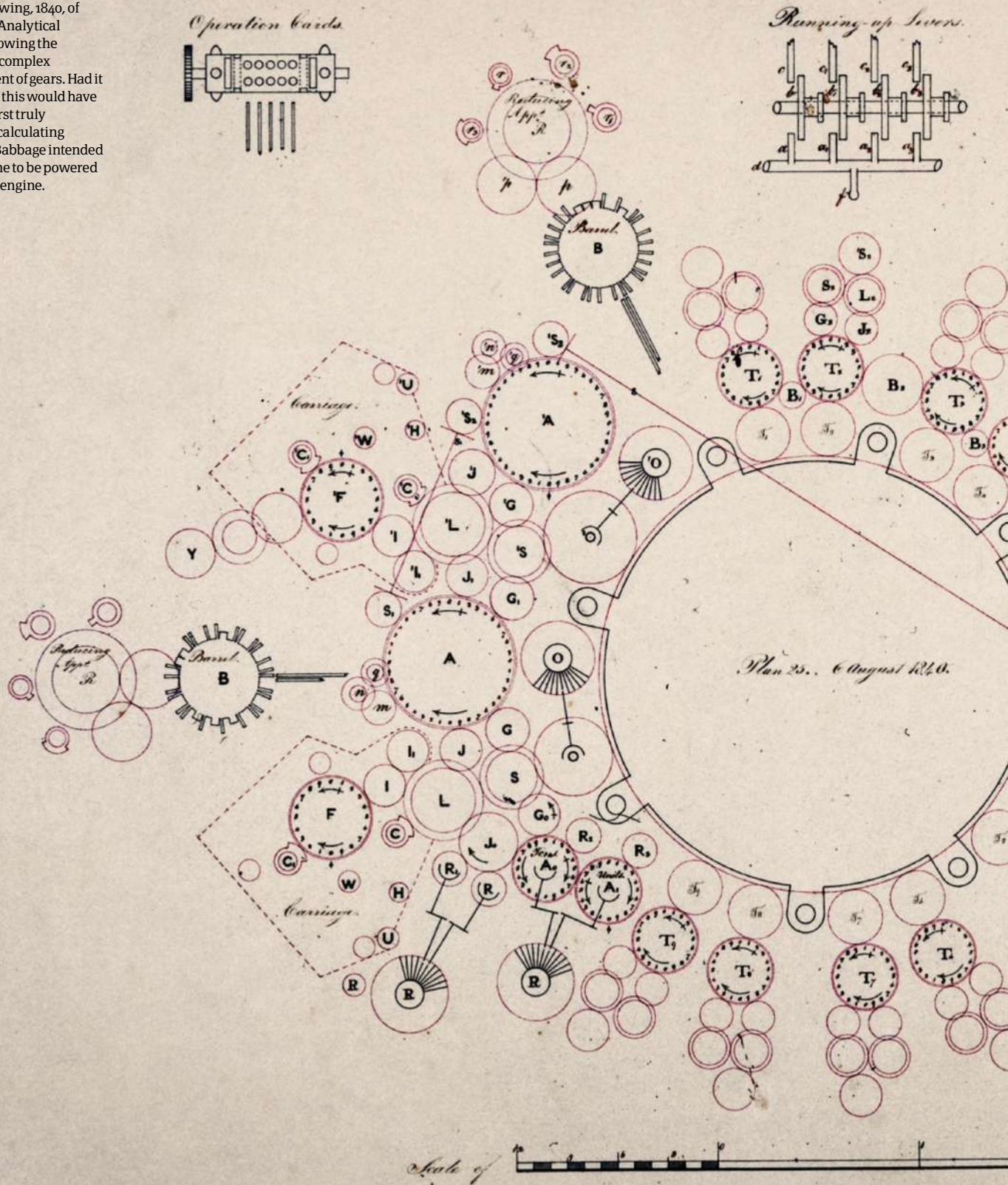
Analytical engine

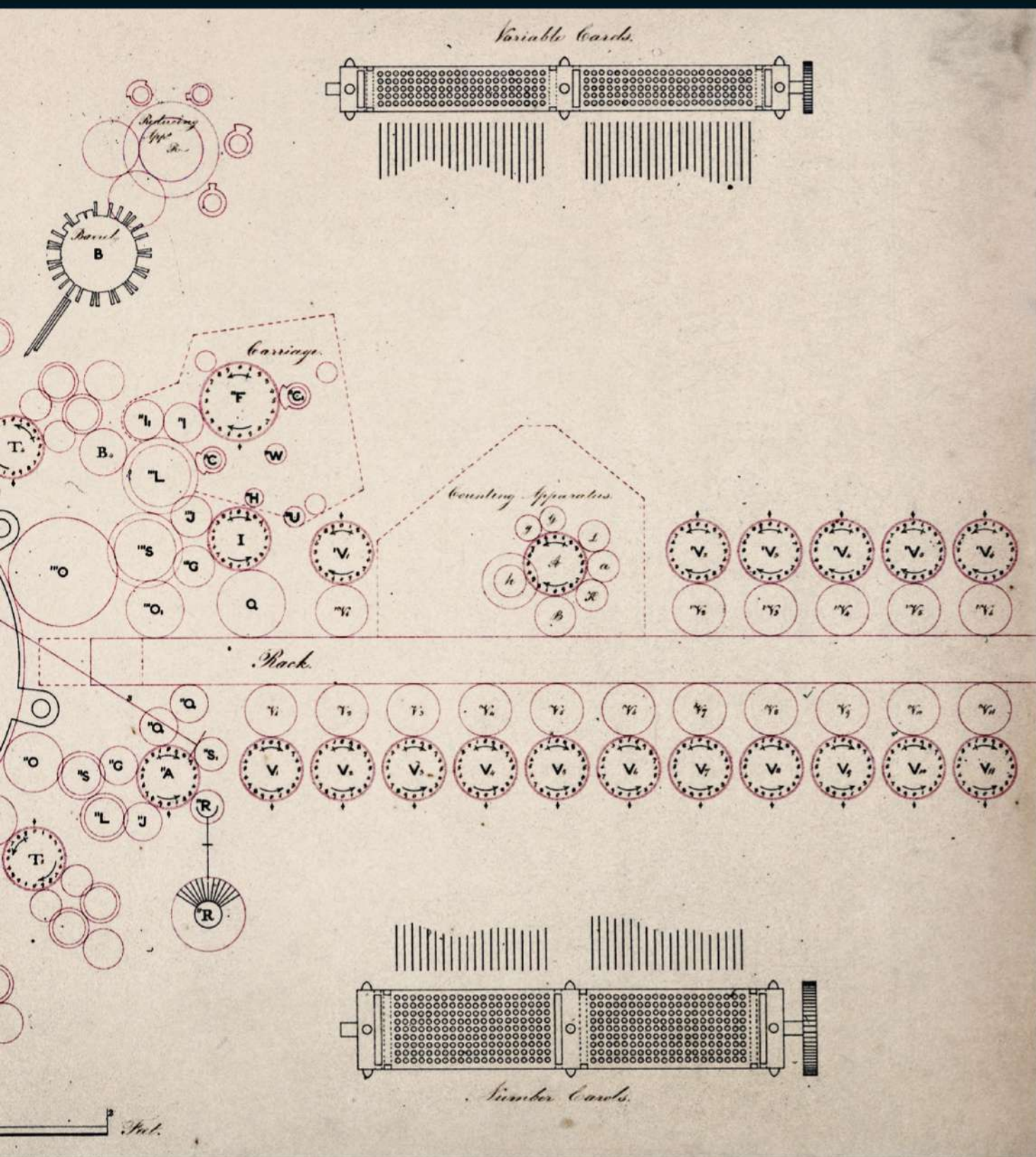
Babbage's Analytical Engine was the first known design for a mechanical, general all-purpose computer. Although never built, the concepts it utilized in its design were at least 100 years before their time. Programs and data would be input using punched cards. Output consisted of a printer, a curved plotter and a bell. The machine's memory would be capable of holding 1,000 numbers of 50 decimal digits each. The programming language it was to use was similar to that used in early computers 100 years later. It used loops and conditional branching and was thus Turing-complete long before Alan Turing's concept (see page 146). Although Babbage's direct influence on the later development of computing is argued greatly, Howard H. Aiken – the primary engineer behind IBM's 1944 Harvard Mark I (the first large-scale automatic digital computer in the United States) – said of Babbage's writings on the Analytical Engine: "There's my education on computers, right there: this is the whole thing, everything took out of a book."



Above: A design sketched by Babbage for part of his Analytical Engine.

Design drawing, 1840, of Babbage's Analytical Engine, showing the incredibly complex arrangement of gears. Had it been built, this would have been the first truly automatic calculating machine. Babbage intended the machine to be powered by a steam engine.







Joseph Lister

(5 April 1827–10 February 1912)

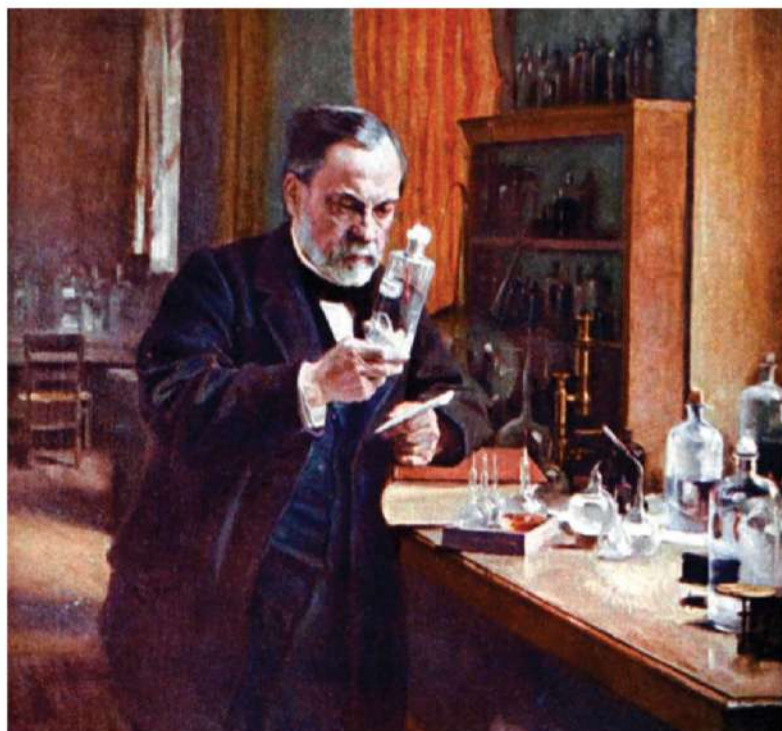
Until the late 19th century, patients undergoing even minor surgery had about as much chance of dying afterwards as they did of surviving. English surgeon Joseph Lister dramatically improved patients' chances in the 1870s, by introducing antiseptics into surgery.

Joseph Lister was born in Upton, in Essex, England, to a wealthy Quaker family. His father was a man of science, who made significant improvements to microscope design. Joseph studied the arts and then medicine at University College, London. Although born and educated in England, he spent most of his career in Scotland.

In 1856, Lister became an assistant surgeon at the Edinburgh Royal Infirmary. Four years later, he was appointed Professor of Surgery at Glasgow University Medical School. In 1861, Lister was put in charge of a new building with surgical wards at Glasgow Royal Infirmary. At the time, around half of the patients died as a result of surgery – open



The surgeon
Joseph Lister in 1902.



Above: French chemist and microbiologist Louis Pasteur in an 1885 painting by Albert Edelfelt (1854–1905). In the 1870s, Pasteur carried out experiments that highlighted the existence of airborne microbes.

wounds often festered, becoming badly infected and inflamed and full of pus. Untreated, this 'wound sepsis' was often life-threatening. The prevailing explanation of infection was the so-called 'miasma theory': the idea that polluted air was the cause of disease. In the filthy air of the disease-ridden cities of the 19th century, this was

an easy connection to make. But it badly missed the point: believing that polluted air caused disease, surgeons carried out operations without washing their hands and surgical wards were not kept clean.

Impressive results

In 1865, Lister read a report by French chemist and microbiologist Louis Pasteur (1822–1895) suggesting that fermentation and rotting are caused by airborne micro-organisms. Pasteur also showed how micro-organisms can be killed by heat, filtration or chemical attack. When Lister heard of Pasteur's work, he realized that airborne micro-organisms might actually be causing wounds to turn septic. He had heard that carbolic acid (phenol, C_6H_5OH) had been used to stop sewage from smelling bad, and had also been sprayed onto fields, where it reduced the incidence of disease in cows. And so, he and his surgeons began applying carbolic acid solution to wounds, and using dressings that had been soaked in the same solution. In 1869, he developed a spray that would fill the air with carbolic acid – the aim being to kill airborne germs. Lister also told his surgeons to wash their hands before and after operations and to wash their surgical instruments in carbolic acid solution. His results were impressive: his surgical wards remained free of sepsis for nine months,

Ignaz Semmelweis (1818–1865)

Nearly 30 years before Joseph Lister's pioneering work on antiseptic surgery, a Hungarian obstetrician, Ignaz Semmelweis, demonstrated the importance of washing hands. He worked in maternity wards at the Vienna General Hospital, in Austria. In wards attended by doctors and medical students, a disease called puerperal fever typically claimed the lives of about 20 per cent of women after childbirth, while in midwife-only wards, the incidence of puerperal fever was much lower.

Semmelweis realized that the doctors and students – who did not wash their hands between operations or even after dissecting corpses – were unwittingly transferring infections from one patient to another. In 1847, Semmelweis began a regime of washing hands with a solution of chlorinated water, and managed to reduce the mortality to below one per cent. Unfortunately, the medical community dismissed Semmelweis's results, and his work was quickly forgotten.

“The doctors and students were transferring infections from one patient to another”





Left: Carbolic acid solution spray, used to sterilize tools and open wounds, as pioneered by Joseph Lister. This example is from France; French surgeons quickly adopted Lister's sterile surgical procedures, in part because it had saved many lives in the Franco-Prussian war.



Right: Glasgow slum, 1868. As in all large cities at the time, poor sanitation and overcrowding led to the spread of infectious diseases. This gave rise to the miasma theory, in which 'foul air' was blamed for disease. The miasma theory was eventually superseded by the germ theory of disease.

and Lister had proved that carbolic acid was an effective antiseptic.

Other surgeons were slow to copy Lister's procedures, largely because many were reluctant to accept the idea that disease can be caused by micro-organisms – an idea known as the 'germ theory of disease'. When, gradually, surgeons did begin using his techniques, post-operative survival rates increased dramatically. It was after surgeons in the Franco-Prussian War of 1870–1871 used Lister's techniques, saving the lives of many wounded soldiers, that Lister's fame spread across Europe, and he began to receive the recognition he deserved. In 1877, Lister moved back to King's College, London, where he managed to convince many of the still-sceptical surgeons by successfully performing a complex knee replacement operation that had nearly always proved fatal. He continued to experiment tirelessly on improving surgical techniques and reducing mortality until his retirement in 1893.

Although Lister is famous for his antiseptic methods, he also worked on 'aseptic' ones: attempting to keep operating theatres free of germs rather than killing them. Scottish surgeon



Lawson Tait (1845–1899) defined modern aseptic surgical practices – even though he was not convinced of the existence of germs. Lister's pioneering investigations into wound sepsis, his application of the germ theory of disease and his success in reducing mortality make his contributions to surgery of utmost importance.

Above: Joseph Lister, centre, directing the use of his carbolic spray during a surgical operation, around 1865. Note the use of a cloth soaked in ether as an anaesthetic (left).



Alfred Nobel

(21 October 1833–10 December 1896)

Few scientists have left a legacy more noble than Alfred Nobel. This Swedish chemist not only invented dynamite, but also urged other scientists to explore new avenues of study by establishing the world's most prestigious accolade for intellectual achievement: the Nobel prize.

Since the award was founded in 1901, the greatest minds have been rewarded for their services to the advancement of science and other arts. This peer-assessed award, Nobel hoped, would inspire people to push the boundaries for the benefit of humanity. Past winners include such geniuses as Albert Einstein, Marie Curie and Alexander Fleming.

Alfred Bernhard Nobel was born in Stockholm, Sweden, on 21 October 1833 to Immanuel and Andriette. His mechanical engineer father enjoyed varying degrees of success with a number of inventing and manufacturing business ventures. In 1837, however, Immanuel left in



ALFRED NOBEL

In the first 20 years after dynamite was patented, 66,500 tons was produced across the globe.



The big idea

Nobel's work with nitroglycerin led him to experiment with different additives to stabilise the oily liquid. One of Nobel's early 'big ideas' was the invention of a functioning detonator, which he designed first as a simple wooden plug and developed into the patented blasting cap, which was fitted with a small primary charge that could be detonated by a strong shock. While the detonators were groundbreaking, it was Alfred's chemistry that really put him on the map.

To make nitroglycerin safer, Nobel spent years developing the formula; several labs and factories were blown up in the process! Before long he discovered that by adding a very fine inert silica powder called diatomaceous earth, or kieselguhr, the oily nitroglycerin liquid could be transformed into a safer, malleable paste. When shaped into rods, this paste could be inserted into drilling holes and detonated in order to blast rock for mining. And the name of this material? Dynamite.

search of better fortune in Russia. By 1842 he had established a profitable business producing equipment for the Russian military, and so the rest of the Nobel family moved out to join him.

Together with his three brothers – Robert, Ludwig and Emil – Alfred was home-educated by private tutors. Taking a cue from his entrepreneurial father, who also designed and made mines, Alfred developed a talent for chemistry – and explosives in particular. In 1850 Alfred travelled to Paris to study chemistry under French professor Théophile-Jules Pelouze, who had been carrying out experiments using concentrated nitric acid to develop explosive materials in his laboratory.

Explosive experiments

On his return to Russia Nobel began working in his father's factory manufacturing military equipment for the Crimean War. Once the conflict was over in 1856, the company struggled to turn a profit and, by 1859, the firm had gone bust, forcing the Nobels to return to Sweden. Alfred's two elder brothers, Robert and Ludwig, remained in Russia hoping to salvage what was left of the business.

Alfred, meanwhile, started experimenting with explosives in his father's lab. By 1862 he had



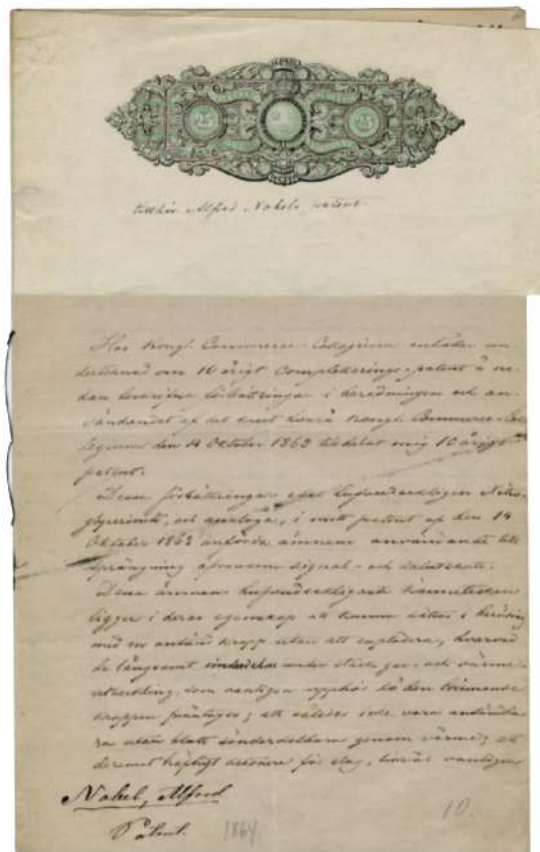
“Nobel spent many years inventing and developing detonation devices”

set up a small factory in which he began to manufacture an exciting but highly volatile explosive called nitroglycerin, which had recently been invented by another of Pelouze's students: Ascanio Sobrero. While Nobel recognised the industrial potential of this explosive, the use of nitroglycerin was just not practical due to its unstable nature. The challenge was to find a way to control nitroglycerin so it could be safely handled.

Nobel spent many years perfecting the formula for his explosives, as well as inventing and developing detonation devices. Eventually his research led him to discover a way to make nitroglycerin stable and practical for the construction and mining industries. This



Nobel was interested in other aspects of chemistry, including the manufacture of synthetic rubber, leather, artificial silk and more.



Above: Nobel's application for patent, regarding his percussion cap and principles for initial ignition of nitroglycerine.

development was the invention of dynamite (see 'The big idea' boxout), for which Nobel obtained the patent in 1867. With a commercial product on his hands, Nobel became a wealthy man at the heart of a brand-new industry. He established some 16 factories for producing explosives in almost as many countries.

Nobel died at the age of 63 of a heart attack at his home in San Remo, Italy. Without the help of a lawyer, a year before his death Nobel had signed his last will and testament. In it he bequeathed much of his wealth to the establishment of an annual prize that he hoped would stimulate scientific progress. In this document he wrote: 'The whole of my remaining realisable estate shall be dealt with in the following way: the capital, invested in safe securities by my executors, shall constitute a fund, the interest on which shall be annually distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit on mankind.'



Above: CCC crew member loading a hole under a stump with dynamite, Lolo National Forest (Montana).



Karl Benz

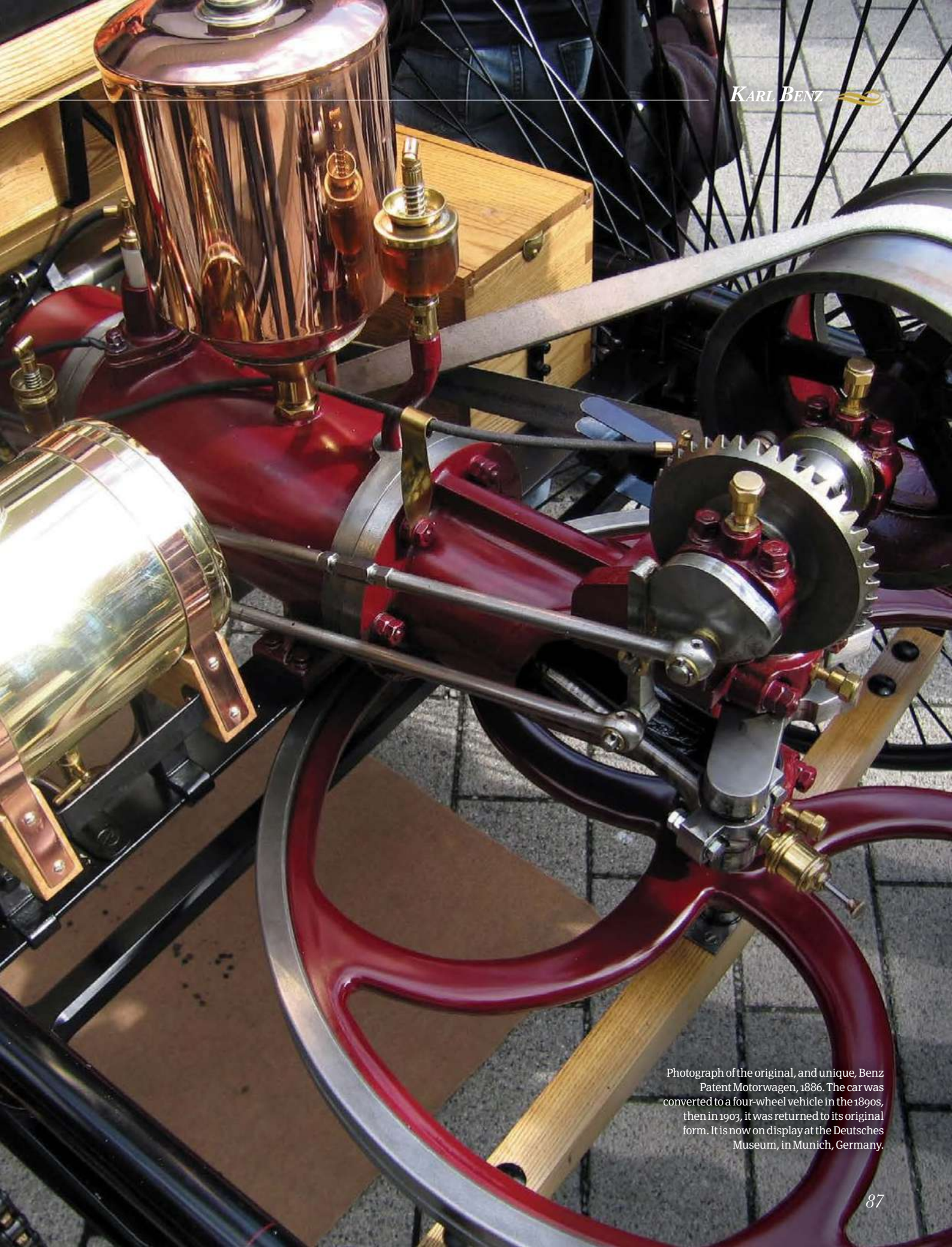
(25 November 1844–4 April 1929)

The person responsible for designing the first true motor car, German engineer Karl Benz, had no idea what effect his invention would have on the world. By increasing mobility, less than 100 years after the rise of the railways, the motor car once again revolutionized patterns of work, play and the distribution of goods, and its rapid uptake in the 20th century changed the landscape very quickly and dramatically.

Karl Benz was born in Karlsruhe, Baden (now in Germany). His father died when Karl was just two years old, but his mother encouraged him greatly, working hard to put him through grammar school and the Karlsruhe Polytechnische Schule (Institute of Technology). It was his dream from very early on to invent a form of transport that would run without horses and off rails.

The idea of self-propelled road vehicles was already popular before Benz was born. Some





Photograph of the original, and unique, Benz Patent Motorwagen, 1886. The car was converted to a four-wheel vehicle in the 1890s, then in 1903, it was returned to its original form. It is now on display at the Deutsches Museum, in Munich, Germany.



Above: Replica of Benz's patent motor car, showing the single-cylinder, four-stroke engine, horizontal flywheel and belt drive. The original ran on ligroin, a mixture of hydrocarbons very similar to petrol. Also visible are the fuel tank, in the foreground, and the cooling water tank.

engineers had made 'cars' – mostly steam carriages and electric vehicles; all of them were adaptations of horse-drawn carts and none was particularly effective. The most crucial invention in the development of the motor car was the internal combustion engine. In a steam engine, the combustion – the fire that heats the steam – is produced outside the cylinder. The first practical engines in which combustion took place inside the cylinder, and drove a piston directly, appeared in the 1850s. The most important was

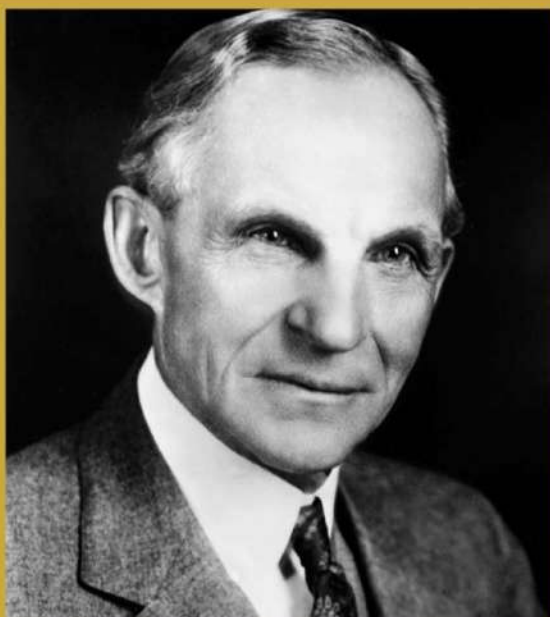
invented in 1859 by Belgian engineer Étienne Lenoir (1822–1900).

The next step towards motor cars proper was the 'four-stroke' engine designed by German inventor Nikolaus Otto (1832–1891) in 1876. The four strokes – intake of the fuel-air mixture; compression of that mixture; ignition; and exhaust – still form the basis of petrol engines today. Otto's engine was the first real alternative to the steam engine.

Motoring dreams

Karl Benz closely followed developments in engine design after leaving college, and worked towards his dream of building a motor car. He had been employed on mechanical engineering projects, and in 1871 had moved to the nearby city of Mannheim. In the 1870s, Benz designed a reliable two-stroke petrol engine (in which the four operations of the four-stroke engine are combined into one upward and one downward stroke), for which he was granted a patent in 1879. Four years later, he formed a company with two other people: Benz & Company Rheinische Gasmotoren-Fabrik. The company began as a bicycle repair shop, and quickly grew when it began making machines and engines.

Benz & Company did rather well, giving Benz the time and the confidence that he needed to



Henry Ford (1863–1947)

For 20 years after Karl Benz's Patent Motorwagen, motor cars were not available to most people. The fact that each one had to be made individually kept the cost high, which in turn kept demand low. In 1908, American entrepreneur Henry Ford set out to change that, when he introduced what he called 'a car for the great multitude'.

The affordable Ford Model T was a real breakthrough, being made from interchangeable parts in a factory with tools laid out in an efficient arrangement. From 1913, the cars were manufactured on assembly lines. One of Ford's employees had seen how effective production lines could be when he visited a meat-packing factory in Chicago. The application of the idea to the motor-car industry brought costs down dramatically, made Henry Ford incredibly rich and had a rapid and profound effect on the world of the 20th century.

“From 1913, the Ford Model T cars were manufactured on assembly lines”



pursue his dream. By the end of 1885, Benz's car was finally ready. It was a three-wheeled carriage powered by a single-cylinder four-stroke engine, which he had created specially. Benz's motor car incorporated several very important innovations of his own design. These included an electric starter coil, differential gears, a basic clutch and a water-cooling system for the engine. Despite his hard work and his obvious brilliance, Benz had not quite worked out how to achieve steering with four wheels. He therefore took the easy option and had three wheels, the single front wheel being turned by a 'tiller'-type handle.

Benz applied for a patent in January 1886, and it was granted in November of that year. His application was successful because his motor car had been designed from the start as a self-

powered vehicle, and not simply as a cart with an engine attached.

After a few improvements, including the world's first carburettor, the first Benz Patent Motorwagen was sold in 1887. Benz began production of the car, and advertised it for sale in 1888; it was the first commercially available production car in history. Uptake was very slow, however, so Benz's wife Bertha (1849–1944) decided to try to raise awareness. In August 1888, she drove with her two sons from Mannheim to her home town of Pforzheim and back – this was a total distance of nearly 200 kilometres (120 miles). The stunt generated a great deal of publicity – and thanks at least in part to that publicity, Benz's Motorwagen ended up becoming a real success. The age of motoring had begun.

Above: By 1888, Benz had improved his design, and began producing cars in greater numbers. French engineer and entrepreneur Émile Roger, in Paris, held the sole rights to sell Benz's cars outside Germany, and helped to popularize the vehicle.

Right: By 1888, Benz had improved his design, and began producing cars in greater numbers. French engineer and entrepreneur Émile Roger held sole rights to sell Benz's cars outside Germany, and helped to popularize the vehicle. Here are extracts translated from the patent granted to Karl Benz for his 'vehicle with gas engine drive'.

IMPERIAL PATENT OFFICE
PATENT NO. 37435
(ISSUED ON 2ND
NOVEMBER, 1896)

CLASS 46: AIR-POWERED
AND GAS-POWERED
MACHINES

BENZ & CO. in MANNHEIM

VEHICLE WITH GAS
ENGINE DRIVE

Patented in the German
Empire as from 29th
January, 1896

The discovery relates to the
operation of mainly light
carriages and small vessels,
such as are used to transport
1 to 4 persons.

The appended drawing
shows a small tricycle-like
vehicle, constructed for 4
persons. A small gas engine
(any system can be used)
serves as the motive power.

The latter receives its gas
from an accompanying
apparatus, in which gas is
generated from petroleum
ether or from other gasifying
materials. The engine's
cylinder is kept at constant
temperature through the
evaporation of water.

The engine is laid out in such
a way that its flywheel
rotates in a horizontal plane
and the power is transmitted
through two bevel gears to
the main wheels. This not
only makes the vehicle fully
manoeuvrable, but also
provides a safeguard against
any tipping over of the same
when being driven around
small curves, or should
there be any obstructions
on the route.

KAISERLICHES PATENTAMT.



PATENTSCHRIFT

№ 37435 —

KLASSE 46: LUFT- UND GASKRAFTMASCHINEN.

BENZ & CO. in MANNHEIM.

Fahrzeug mit Gasmotorenbetrieb.

Patentirt im Deutschen Reiche vom 29. Januar 1886 ab.

Vorliegende Construction bezweckt den Betrieb hauptsächlich leichter Fuhrwerke und kleiner Schiffe, wie solche zur Beförderung von 1 bis 4 Personen verwendet werden.

Auf der beiliegenden Zeichnung ist ein kleiner Wagen nach Art der Tricycles, für 2 Personen erbaut, dargestellt. Ein kleiner Gasmotor, gleichviel welchen Systems, dient als Triebkraft. Derselbe erhält sein Gas aus einem mitzuführenden Apparat, in welchem Gas aus Ligroin oder anderen vergasenden Stoffen erzeugt wird. Der Cylinder des Motors wird durch Verdampfen von Wasser auf gleicher Temperatur gehalten.

Der Motor ist in der Weise angeordnet worden, daß sein Schwungrad in einer horizontalen Ebene sich dreht und die Kraft durch zwei Kegelräder auf die Triebräder übertragen wird. Hierdurch erreicht man nicht nur vollständige Lenkbarkeit des Fahrzeuges, sondern auch Sicherheit gegen ein Umfallen desselben beim Fahren kleiner Curven oder bei Hindernissen auf den Fahrstraßen.

Die Kühlung des Arbeitscylinders des Motors geschieht durch Wasser, welches die ringförmigen Zwischenräume ausfüllt. Gewöhnlich läßt man das Kühlwasser bei Gasmotoren mit geringer Geschwindigkeit durch den Cylinder sich bewegen, indem das kalte unten eintritt und das erwärmte oben abfließt. Es ist aber dazu ein großer Wasservorrath nöthig, wie ihn leichte Fuhrwerke zu Land nicht gut mitführen können, und daher folgende Einrichtung getroffen worden: Das Wasser um den Cylinder verdampft. Die Dämpfe streichen durch das oberhalb des Cylinders angebrachte Rohr-

system 1, werden dort zum größten Theil condensirt und treten wieder als Wasser unten in den Cylinder ein. Der nicht condensirte Dampf entweicht durch die Oeffnung 2.

Das zum Betrieb des Motors nöthige Gas wird aus leicht verdunstenden Oelen, wie Ligroin, dargestellt. Um stets ein gleichmäßiges Gasgemenge zu erhalten, ist es nöthig, daß neben dem gleichmäßigen Lufzutritt und der gleich hohen Temperatur des Ligroins auch der Stand des letzteren im Kupferkessel 4 ein möglichst gleicher sei, und ist zu diesem Zweck der Vorrathsbehälter 5 mit dem Kupferkessel 4 durch eine enge Röhre 6, die in ein weites Wasserstandsglas 7 mündet, verbunden. An der Röhre ist ein kleiner Hahn 8 angebracht, um den Zufluß nach Bedarf reguliren zu können. Durch die Glasröhre ist das tropfenweise Eintreten des frischen Ligroins wahrzunehmen und zugleich der Stand desselben im Apparat zu controliren.

Das Ingangsetzen, Stillhalten und Bremsen des Fuhrwerkes geschieht durch den Hebel 9. Der Motor wird, bevor man den Wagen besteigt, in Betrieb gebracht. Dabei steht der Hebel 9 auf Mitte. Will man das Fuhrwerk in Bewegung setzen, so stellt man den Hebel 9 nach vorn, wodurch der Treibriemen vom Leerlauf auf die feste Scheibe geschoben wird. Beim Anhalten bewegt man den Hebel 9 wieder auf Mitte, und will man bremsen, so drückt man ihn über Mitte rückwärts. Der ausgerückte Riemen bleibt dabei in seiner Stellung und nur die Bremse wird angezogen. Um zu bewirken, daß, wenn der Riemen auf Leerlauf gestellt ist, derselbe bei weiterer Rück-



KAISERLICHES

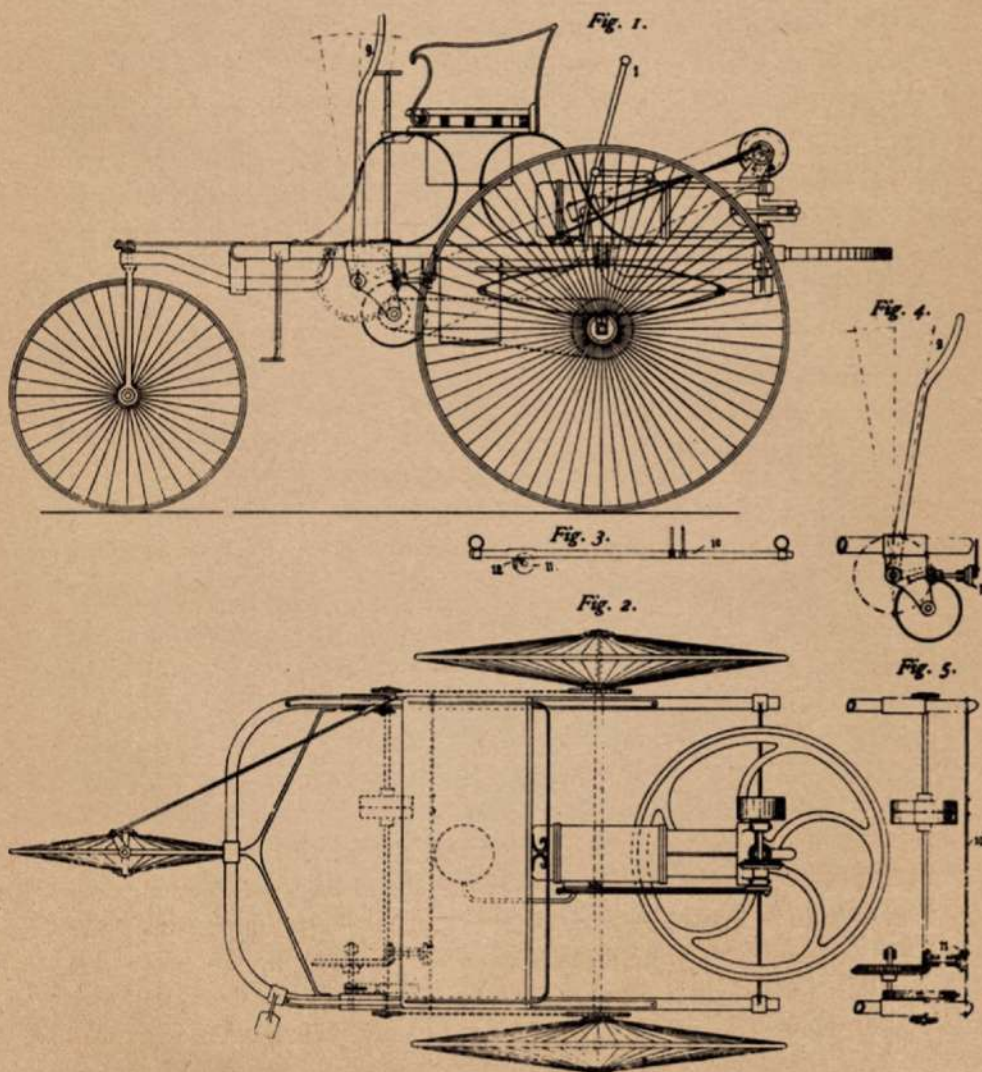
PATENTAMT.

PATENT-SCHRIFT

— № 37435 —

KLASSE 46: LUFT- UND GASKRAFTMASCHINEN.

AUSGEZEIGT DEN 2. NOVEMBER 1886





Thomas Edison

(11 February 1847–18 October 1931)

For the sheer number of important inventions he pioneered, Thomas Edison is one of the best-known and most prolific inventors of all time. He was granted a total of 1,093 US patents, but perhaps his greatest invention of all was something he could not patent: organized, systematic research.

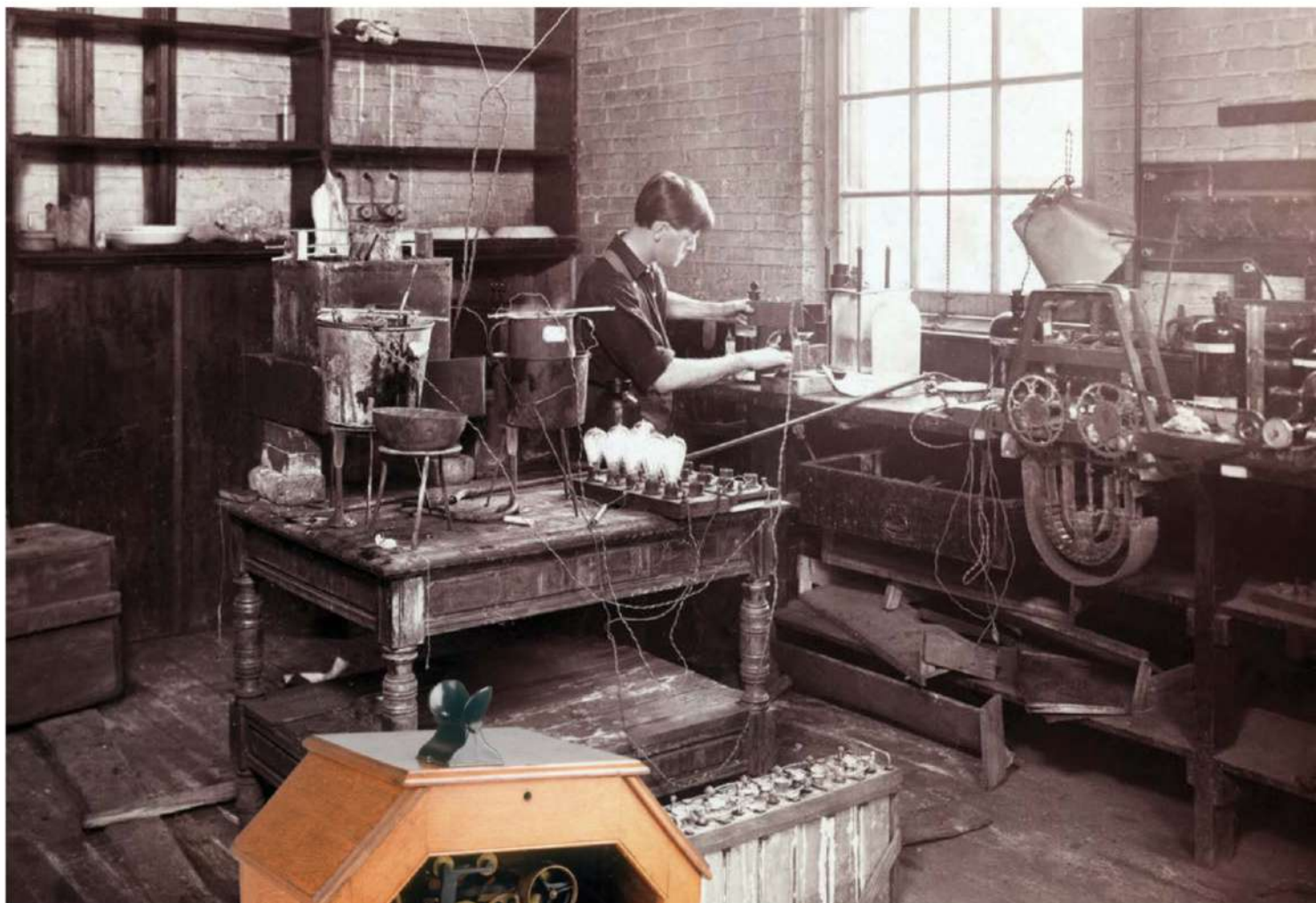
Home-schooled from the age of 12, Edison set up his first laboratory in his bedroom at his family's home in Port Huron, Michigan. Much of his early effort was dedicated to improving the telegraph, a system that had revolutionized long-distance communication in the 1840s. At 14, Edison built a working telegraph at home; by the age of 16, he was working as a telegraph operator at his local telegraph office; and for the next five years he travelled, working at a number of telegraph offices in several cities. Eventually, he decided to devote all his time to inventing.

Edison's first successful invention was the 'Universal Stock Ticker' (1870) – a device with



Photograph of Edison with his phonograph (2nd model), taken in Mathew Brady's Washington, DC studio in April 1878.





Above: The galvanizing room in Edison's Menlo Park laboratory. His early electric bulbs can be seen on the table.

Right: One of the most important early inventions to come from West Orange, in 1894, was the Kinetoscope, the first device for showing moving pictures. Edison came up with the idea after meeting English inventor Eadweard Muybridge, who pioneered the photography of movement. The Kinetoscope and an associated camera were developed by a British assistant of Edison, WKL Dickson, and led to the invention of cinema.



which dealers could receive the current share prices across the telegraph system, from the New York Stock Exchange. He sold the rights to this invention, and with the money he made, he set up a workshop in Newark, New Jersey, in which he employed 80 people. One of his employees was 16-year-old Mary Stilwell, who became his first wife in 1871.

Other inventions

In 1873, he invented the 'Quadruplex Telegraph', which made it possible to transmit and receive four telegraph signals simultaneously on a single wire. He sold the rights to this invention to Western Union – it saved them millions of dollars in wiring – and the proceeds helped him move his workshop to new premises. In 1876, Edison bought 34 acres (14 hectares) of land in the countryside of Menlo Park, New Jersey, where he



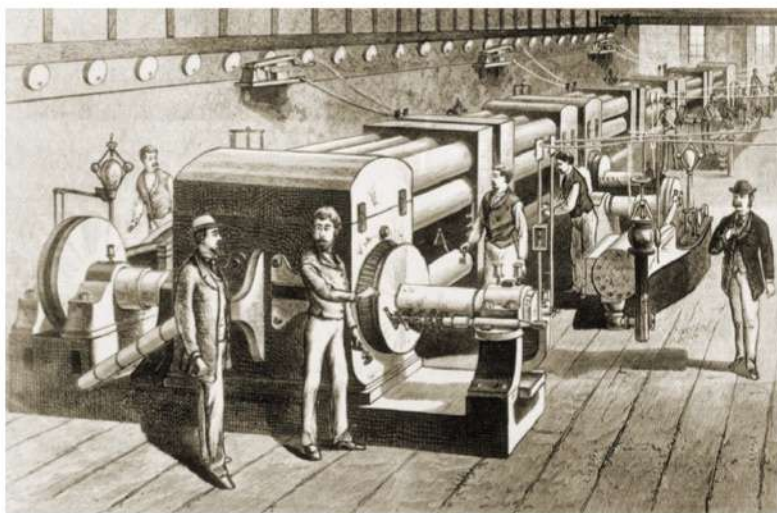
The phonograph

In July 1877 Edison came up with an idea for a device that would make it possible to record and play back sounds. One of his researchers set about trying to make it, and in November Edison recited the first verse of the poem “Mary Had a Little Lamb”. To everyone’s amazement, the device played back Edison’s voice clearly. The phonograph indented sound vibrations on to a sheet of tinfoil wrapped around a cylinder, turned by a hand crank.

set up a full research and development laboratory – the first of its kind anywhere in the world. At Menlo Park, Edison set about trying to improve the recently-invented telephone. In 1877, he invented a sensitive microphone, filled with compressed carbon, which improved the distance over which telephone calls could be made. His invention was part of nearly every telephone until the 1970s.

As an offshoot of his research into the telephone, Edison and his team invented a device for recording sound: the phonograph. It was an instant success, and Edison travelled extensively to demonstrate his new invention. He was even called to the White House to show it to the then US President, Rutherford Hayes. One journalist referred to Edison as the Wizard of Menlo Park – a name that stuck.

Perhaps the most important invention to come out of Menlo Park was the light bulb. As is true of nearly all his inventions, Edison did not actually invent the light bulb: he made significant



Above: The Dynamo Room at Pearl Street Station, New York. Pearl Street, the first central power plant in the US, was built by Edison’s Electric Illuminating Company and started generating electricity on 4 September 1882. By 1884 it was serving 508 customers and powering 10,164 lamps.

improvements that made it practicable for the first time. His use of a carbonized bamboo filament meant a bulb would light for 40 hours instead of just a few minutes. He demonstrated the new technology in December 1879, lighting the workshop in a public demonstration.

Edison set up a bulb-making factory at Menlo Park, and his success with electric light led him to work on a system to distribute electric power. He patented the system in 1880, and by 1882, he had set up a power station at Pearl Street, New York.

In 1884, Edison’s wife died. He married again, to Mina Miller, in 1886. The following year, Edison moved his operation to a new laboratory in West Orange, also in New Jersey. He headed the West Orange laboratory until his death in 1931. During this period, his research team invented the first device for showing moving pictures (using 35mm sprocketed film, which later became the film industry standard), a new type of battery, a device for separating iron ore, an all-concrete house, and an electric locomotive.

After Edison died, US President Herbert Hoover encouraged Americans to turn off their lights for one minute, in tribute to the contributions made by America’s greatest inventor.



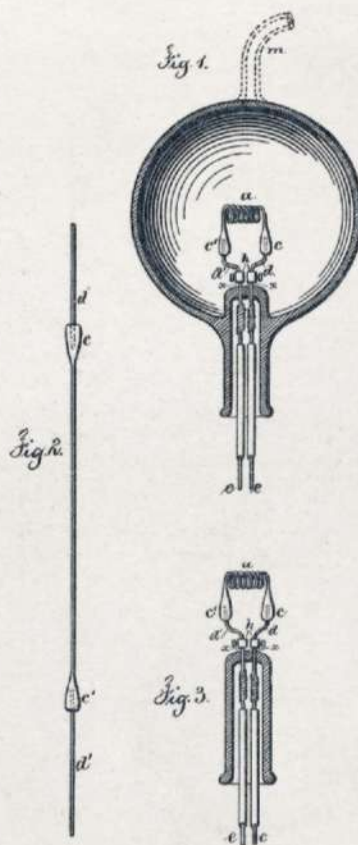
Above: An ‘Ediswan’ lamp, c.1890. English physicist Sir Joseph Wilson Swan (1828–1914) took Edison’s lamp and improved upon it further.

“Edison did not invent the light bulb: he made improvements that made it practicable”

Right: Diagram from Edison's 1880 patent for an 'electric lamp'.

Edison's main innovation was to use a long, coiled filament; figure 2 shows the filament before coiling. Coiling allowed Edison to fit a long filament inside a small bulb, dramatically increasing the filament's resistance.

T. A. EDISON.
Electric-Lamp.
No. 223,898. Patented Jan. 27, 1880.



Witnesses
Chas. H. Smith
Geo. D. Pinckney

Inventor
Thomas A. Edison
for Lemuel W. Ferrell

cut

THE MERRILL MEYER CO. PHOTOGRAPHS, WASHINGTON, D. C.



Left: Drawing for a Phonograph, 05/18/1880. This is the printed patent drawing for a phonograph invented by Thomas A. Edison. From the National Archives.

2 Sheets—Sheet 2.

T. A. EDISON.
Phonograph.

No. 227,679.

Patented May 18, 1880.

Fig. 4.

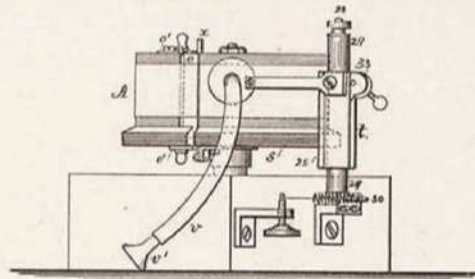


Fig. 3.

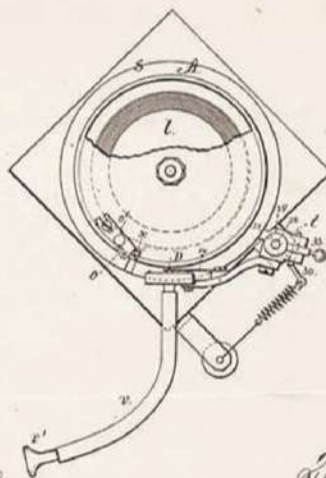
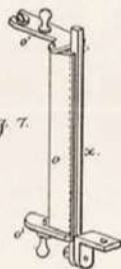


Fig. 7.



Witnesses:
Harold Serrell
Charles H. Smith

Inventor:
Thomas A. Edison
per Lemuel W. Persell
att.

THE HUBBARD PETERS CO. PHOTO-LITHO., WASHINGTON, D. C.



Alexander Graham Bell

(3 March 1847–2 August 1922)

Probably the most lucrative patent of all time was awarded to a Scottish-Canadian-American inventor in 1876, for a device that had the magical ability to transmit the sound of the human voice across long distances. The inventor's name was Alexander Graham Bell, and the device was the telephone.

Alexander Graham Bell was born in Edinburgh, Scotland. His father and grandfather were pioneers in the field of speech and elocution, and his mother had a condition that resulted in progressive hearing loss. These influences inspired Bell to study language and the human voice. The young Bell attended a prestigious school in Edinburgh, and when he left aged 16, he taught music and elocution before studying in Edinburgh and London. After his studies, Bell taught deaf people to speak, using a method his father had developed, and it was during this time he began experiments in the transmission of sound using electricity.

Top left portrait photo ©MoffettStudio

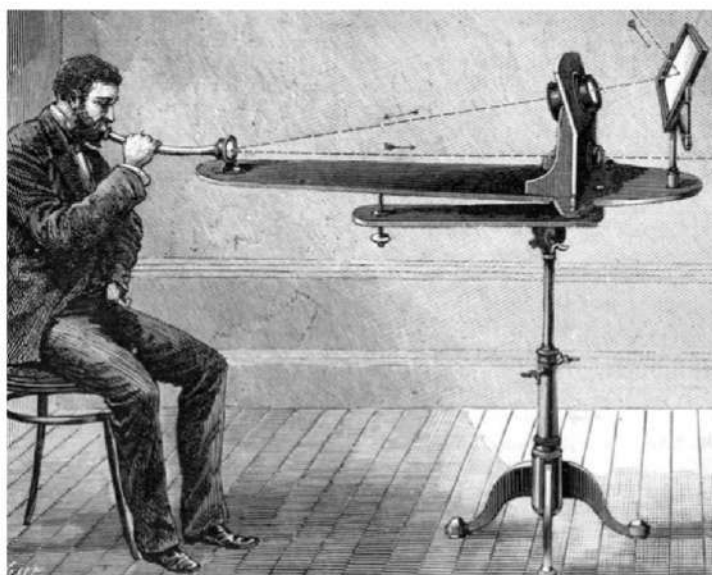




Alexander Graham Bell, seated, in New York, on 18 October 1892, at the opening of the first long-distance telephone service. The line connected New York and Chicago, in the USA: a distance of about 1,140 kilometres (710 miles).



Above: In 1877, news of Bell's success spread worldwide. Britain's Queen Victoria even asked Bell to demonstrate it at her residence on the Isle of Wight. This telephone and 'terminal panel' were part of the resulting installation.



Above: The first wireless telephone call, using a photophone transmitter, in April 1880. Sound made a tiny mirror vibrate inside the transmitter, which changed the intensity of a light beam reflected off it. At the receiver, a light-sensitive cell detected the changes in intensity and reproduced the speech sounds.

Bell lost both his brothers to tuberculosis, and in 1870 his own precarious state of health deteriorated. His parents decided the family should emigrate to Canada. Within a year of arriving, Bell had become a Canadian citizen, and his health had improved. The family settled on a farm, and Bell continued his experiments with sound and electricity. He spent time teaching deaf people in Montreal, Canada, and in various American cities. Eventually, he settled in Boston, where he founded a school for the deaf and became professor of vocal physiology at Boston University. However, in 1873, becoming increasingly preoccupied with his attempts to transmit sound with electricity, he resigned his position. He retained two deaf people as private students; as luck would have it, their wealthy parents became interested in what he was trying to achieve, and helped fund his work.

By 1874, Bell had built a device called a harmonic telegraph, which was designed to transmit several telegraph messages at the same time through a single wire. Each message was

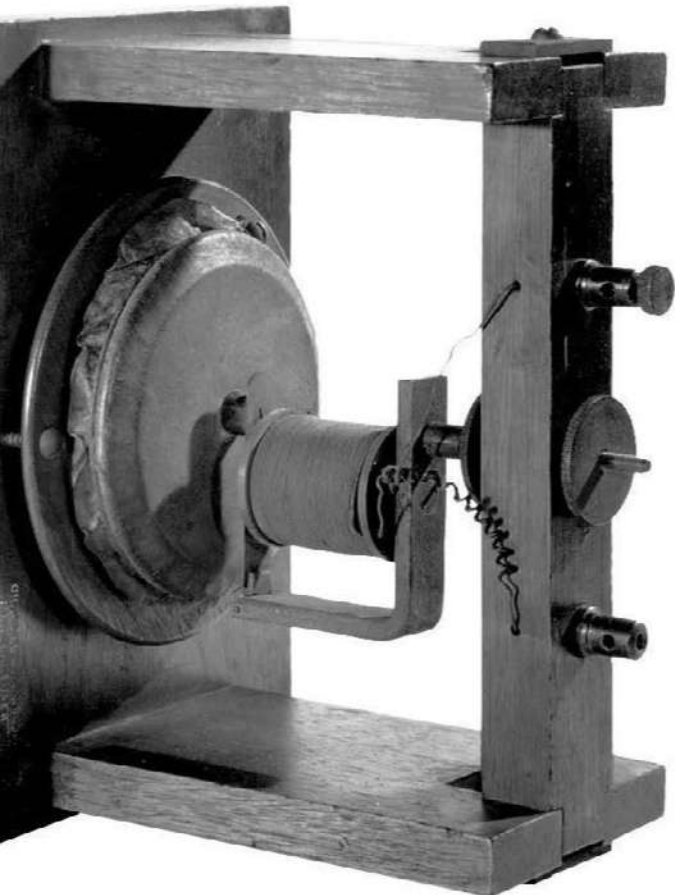
sent as pulses of electricity with a distinct frequency of alternating current. Bell's financial backers were keen for him to perfect his device, but Bell was much more interested in trying to adapt his device to transmit the human voice through a wire, something that many thought was impossible. In 1875, Bell was getting close, but his knowledge of electricity was lacking. Fortunately, that year he met an electrical technician called Thomas Watson (1854–1934), whom he engaged as his assistant.

Success

When Bell was granted the patent for the telephone, his device had not yet transmitted any speech. But three days later, on 10 March 1876, Bell and Watson achieved success. Bell, in one room, spoke into the device, and in an adjoining room, Watson heard the now famous words, "Mr Watson, come here – I want to see you." In the following months, Bell and Watson made improvements to the microphone, and his device transmitted speech over increasing distances – and began to generate huge interest from scientists as well as the press. In 1877, he and his financial backers formed the Bell Telephone Company.

Bell's inventions were not only restricted to the telegraph and the telephone. He improved

“Bell improved Edison's most famous creation: an early sound-recording device, the phonograph”



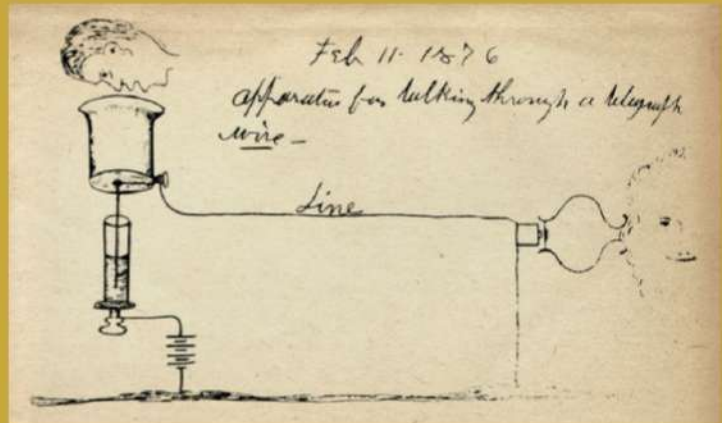
Above: Replica of Bell's 1875 experimental telephone transmitter. Speech sounds caused the stretched parchment drum to vibrate, and the metal spring with it. A magnet attached to the spring produced an alternating electric current in the coil that matched vibrations of the sound waves.

Edison's most famous creation: an early sound-recording device known as the phonograph. He also invented record-breaking speedboats that rose up out of the water on submerged 'wings' called hydrofoils, a chamber to help people with respiratory problems breathe better (an early version of the iron lung) and the first metal detector. In his later years, he spent a great deal of time and effort experimenting with flight. The invention of which he was most proud, however, was the photophone, a device that transmitted sound using light rather than electricity. In 1880, Bell's photophone made the first ever wireless transmission of speech, across a distance of more than 210 metres (230 yards). Although his idea never actually took off at the time, it is very similar to the way telephone signals are transmitted today using laser light passing through optical fibres.

Elisha Gray (1831-1901)

Alexander Graham Bell's company fought a total of 587 lawsuits over priority in the invention of the telephone during the 1880s and '90s. The company won them all, ultimately due to the fact that no one had claimed priority until many months after Bell was awarded his patent. However, some controversy remains over Bell and one of his competitors at the time: prolific American inventor Elisha Gray.

On the same day as Bell filed his patent, 14 February 1876, Gray filed a patent 'caveat' at the same office, for a very similar device. There is evidence that Bell had sight of Gray's application. In Bell's first successful experiment, he used a water-based microphone Gray had designed. But he never used it in public demonstrations, probably because he knew he should not have known about it. Instead he used his own, less effective, electromagnetic receiver.



Above: Bell's HD-4 hydrofoil boat, photographed in 1919, when it set a marine speed record of 114.04 kilometres (70.86 miles) per hour. Bell became interested in hydrofoils just after the Wright Brothers had successfully lifted into the air with aerofoils.



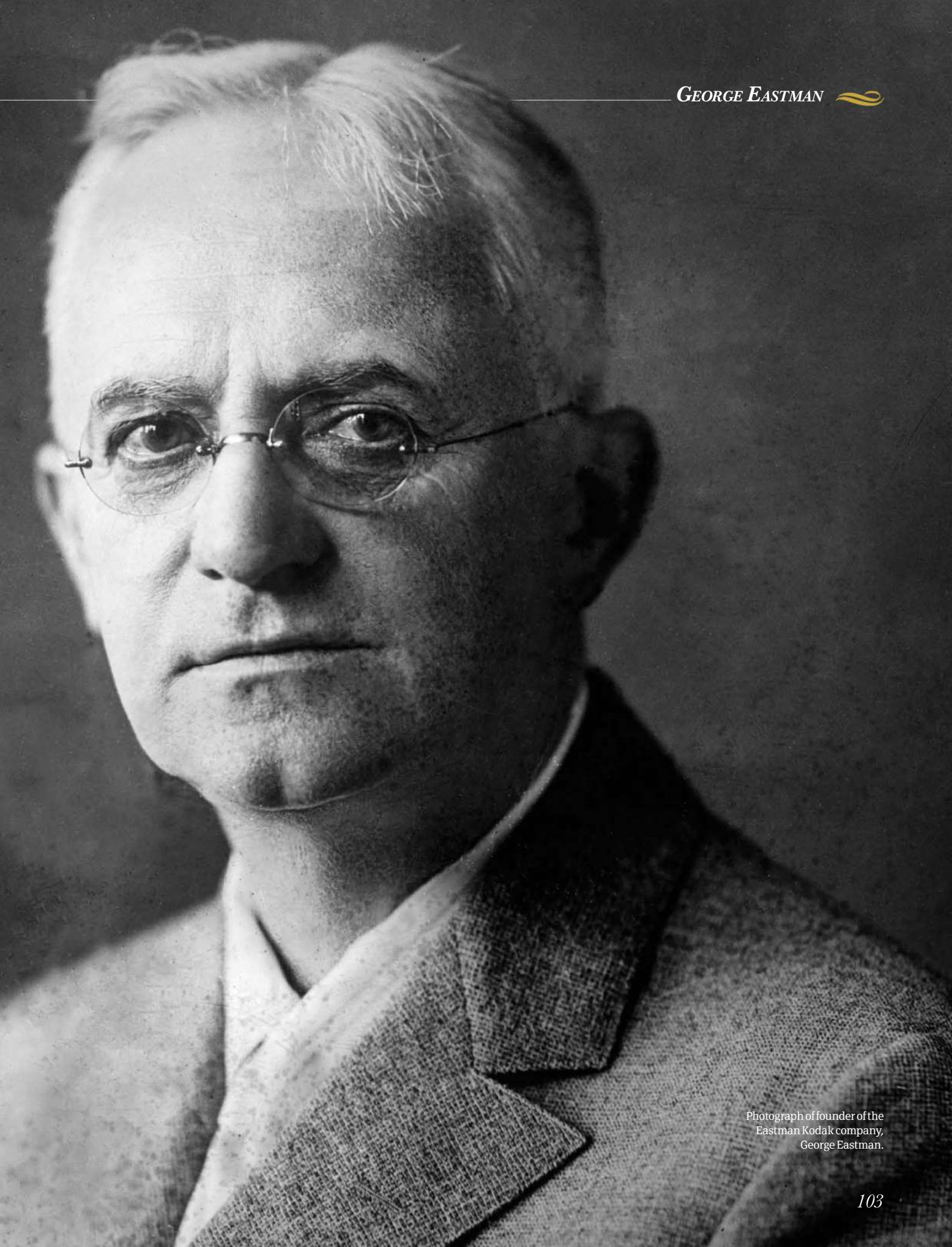
George Eastman

(12 July 1854–14 March 1932)

In its first fifty years, photography was the preserve of a relatively small number of professionals and enthusiastic amateurs. It was expensive, time-consuming, awkward and very specialized. All that changed in 1888, when American inventor George Eastman began selling a cheaper camera, which was also easier to use.

George Eastman was born on a small farm in New York State, USA. When he was five years old, the family moved to the city of Rochester, also in New York. His father died when George was just eight years old, and the family fell on hard times. As a result, George had to leave school aged 13, to find a job. He was keen to learn, though, and was largely self-taught.

Eastman's interest in photography was sparked at age 24 when, while working as a bank clerk, he planned a trip abroad. A colleague suggested he take a record of his trip, so Eastman bought a camera. The camera was a large, unwieldy box, which had to be mounted on a heavy tripod and



Photograph of founder of the
Eastman Kodak company,
George Eastman.



Above: Taking a photo with a Kodak Brownie camera, 1900s. Brownie cameras transformed photography from an expensive, technically-challenging process to something a child could master and more could afford.

instead of film there were individual glass plates that had to be coated with light-sensitive emulsion in situ and held in large plate holders. For outdoor shooting, the plates had to be prepared in a portable tent that doubled as a darkroom.

In 1878, Eastman read about 'dry plates', invented in 1871 by the English photographer Richard Leach Maddox. The emulsion was sealed onto the plates with gelatine. These plates could be stored then used whenever desired, making obsolete much of the equipment Eastman had

bought. While he was still working at the bank, Eastman devoted all his spare time to finding the perfect way to mass-produce dry plates.

Convenience

In 1880, Eastman set up the Eastman Dry Plate Company. He began making and selling dry plates in 1881, and realized that glass could be replaced by a lighter, flexible material. In 1884, he had the idea of making the flexible plate into a roll. A roll holder could be mounted in place of the plate holder inside the camera. His first camera to feature a roll of film, dubbed the 'detective camera', was available in 1885. The roll was made of paper, but this was not ideal since the grain of the paper showed up on the prints. Meanwhile, other people were working on flexible dry plates, too. Several were experimenting with a material called nitrocellulose, also known as celluloid. Eastman began selling celluloid film in 1889.

Eastman's real stroke of genius was his realization that, to be successful, he would need to expand the market for photography, and that would mean, in Eastman's own words, making photography "as convenient as a pencil". To do that, he had to invent a new, smaller, affordable camera. In 1888, the first Kodak camera went on sale. It was an immediate success.

The camera came loaded with a roll able to record 100 photographs. Once a camera's owner

“Eastman's stroke of genius was his realization that, to be successful, he'd need to expand the market for photography”

The Brownie

The first camera with mass-market appeal, the Kodak, retailed at \$25 (5 shillings in the UK). This was only half what Eastman paid for the first camera he bought, but it was still prohibitively expensive for everyday photography. In 1900, the Eastman Kodak Company introduced the first of its most successful range of cameras: the Brownie. Eastman Kodak made and sold 99 different models of Brownies between 1900 and 1980.

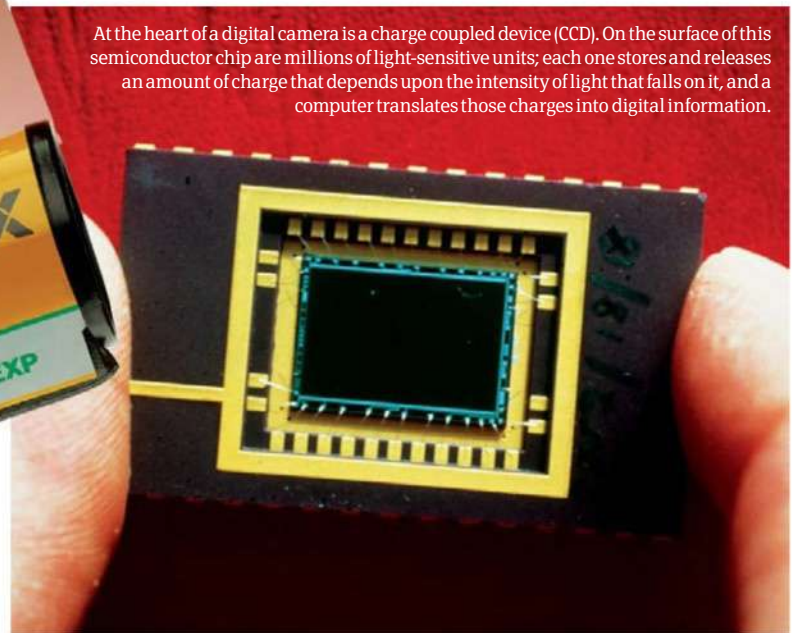
The first Brownie was a cardboard box that contained a roll holder, a roll of film and a lens. On the outside, there was a shutter button and a spool winder. The epitome of simplicity, it sold for just \$1 (equivalent to about \$20 in 2010), and brought in the era of the 'snapshot' - a photograph taken without preparation that can capture a moment in time which would otherwise be lost.



George Eastman using a 16-mm Cine-Kodak camera.



Above: Dry plate camera, 1870s. Photography took off with the advent of 'wet plates' (1850) – glass slides coated in wet, light-sensitive solution. Convenient and affording shorter exposure times, Eastman's first success was mass-producing them.



At the heart of a digital camera is a charge coupled device (CCD). On the surface of this semiconductor chip are millions of light-sensitive units; each one stores and releases an amount of charge that depends upon the intensity of light that falls on it, and a computer translates those charges into digital information.

Above: After its introduction to still photography in 1925, 35mm roll film dominated the market until the introduction of consumer digital cameras in the 1990s.

Top: The Eastman Dry Plate Company building, in New York. Eastman moved to this building in 1883, after the commercial success of his dry plates.

had taken the pictures, he or she had only to send the camera to Eastman's company and wait for the pictures and the return of the camera, newly loaded with film. The key to the Kodak's success was changing the perception of photography to something that anyone could do. Eastman had a simple phrase that did just that: "You press the button, we do the rest."

Eastman changed the name of his company to Eastman Kodak, and cornered the market in

affordable photography. He never married, nor did he ever have any children.

He was a great philanthropist, giving away large sums of his own money to universities, hospitals and dental clinics. His last two years were painful because he was suffering from a degenerative bone disease, and he ended up taking his own life in 1932 by shooting himself in the heart. His suicide note read: "My work is done; why wait?"



Nikola Tesla

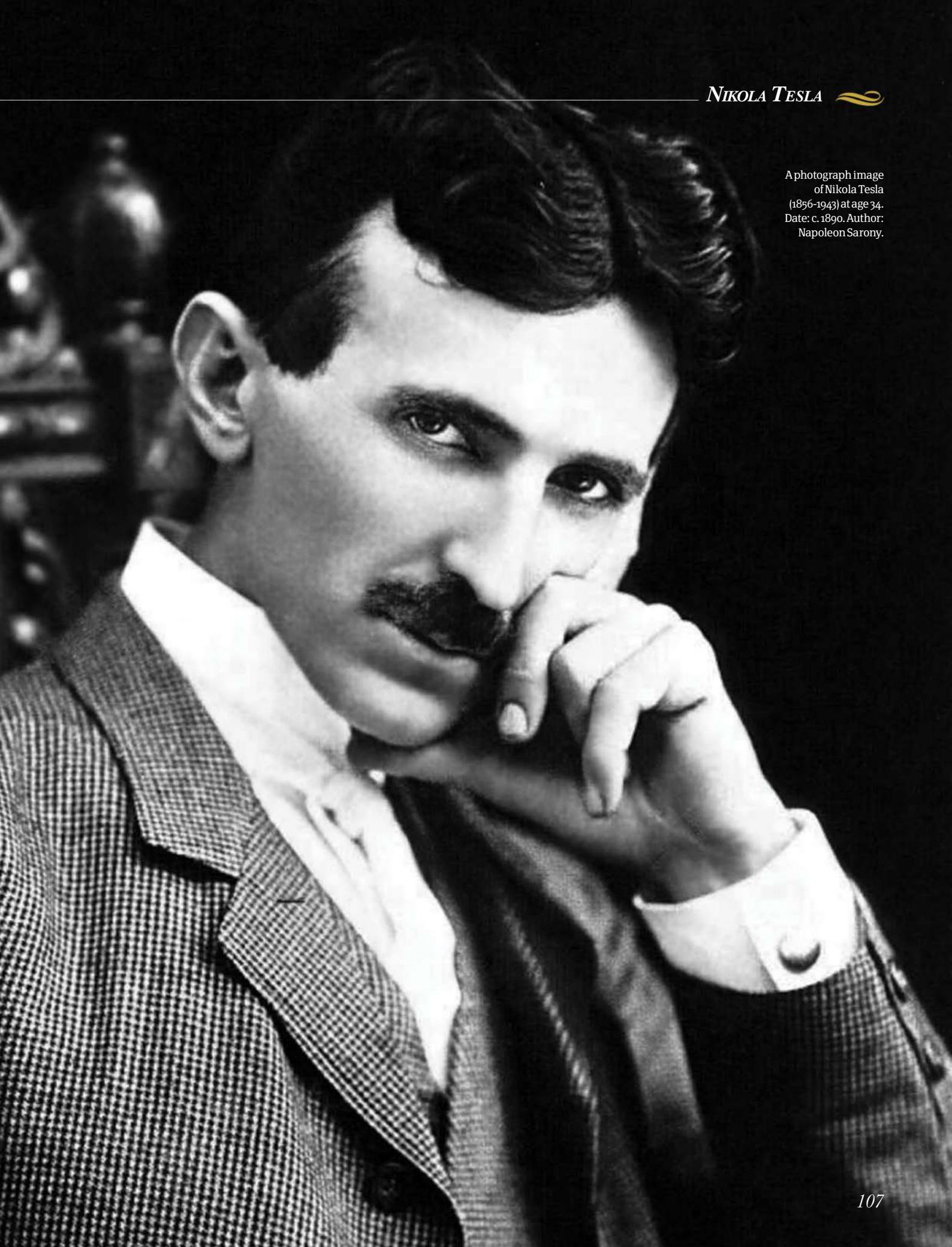
(10 July 1856–7 January 1943)

Serbian-American genius Nikola Tesla would be very MUCH at home in today's developed world, with its almost ubiquitous electricity supply and its widespread reliance on wireless technologies. His vision and determination went a long way towards creating it.

Nikola Tesla was born into a Serbian family in Smiljan, now in the Republic of Croatia but at the time of his birth part of the Austrian Empire. He studied engineering, first in Austria then in Prague, where he dropped out after a few months as his father died. Nevertheless, in 1880, he landed a job as a telephone engineer in Budapest.

In 1882, Tesla had a flash of inspiration that resulted in one of his most important inventions: the AC (alternating current) motor. AC is electric current that repeatedly changes the direction it flows along a wire, unlike DC (direct current), which flows in one direction only. Inside Tesla's motor, AC passes through a clever arrangement of coils, producing a rotating magnetic field that

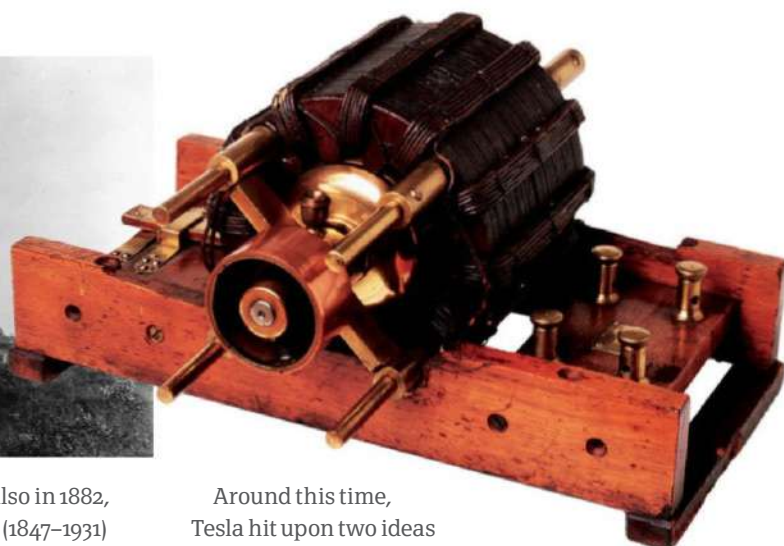
A photograph image
of Nikola Tesla
(1856-1943) at age 34.
Date: c. 1890. Author:
Napoleon Sarony.





Above: Wardencliff Tower, 57 metres (187 feet) high, with metal pipes pushing 125 metres (400 feet) into the ground. Tesla hoped that electrical oscillations would 'shake' the earth and travel through the atmosphere, enabling the worldwide broadcasts of sound and pictures.

Top Right: A demonstration model made by Tesla of an induction motor – perhaps Tesla's most important invention – stripped down to show the coils of wire (stator) surrounding the rotor. Alternating current in the stator creates a rotating magnetic field, which pulls the rotor around.



spins the rotor (the rotating part). Also in 1882, American inventor Thomas Edison (1847–1931) opened the world's first steam-driven power-generating stations, one in London and one in New York; both produced DC, which Edison favoured because no AC motors were available, and Edison's light bulbs – the main reason for generating power at the time – did not work well with AC.

Tesla worked for a year for an Edison subsidiary in France, and in 1884 he moved to America. All he had was 4 cents and a letter of recommendation from his boss to Edison himself. Edison gave Tesla a job, and also promised him \$50,000 if he could improve on Edison's DC generators. Within a year, Tesla had succeeded, however, Edison was not forthcoming with the money. Tesla asked for a raise instead, but was again refused, and he subsequently resigned.

Bigger and better things

During the months that followed, Tesla developed a power distribution system based on AC; he took out several patents in 1887. Alternating current power distribution is cheaper to install, more efficient and more versatile than DC systems. American inventor George Westinghouse (1846–1914) was impressed with Tesla's ideas, and in 1888 he gave Tesla a job. There ensued a battle between Edison (DC) and Westinghouse (AC), but Tesla's system won out, and his AC motor has driven the wheels of industry ever since.

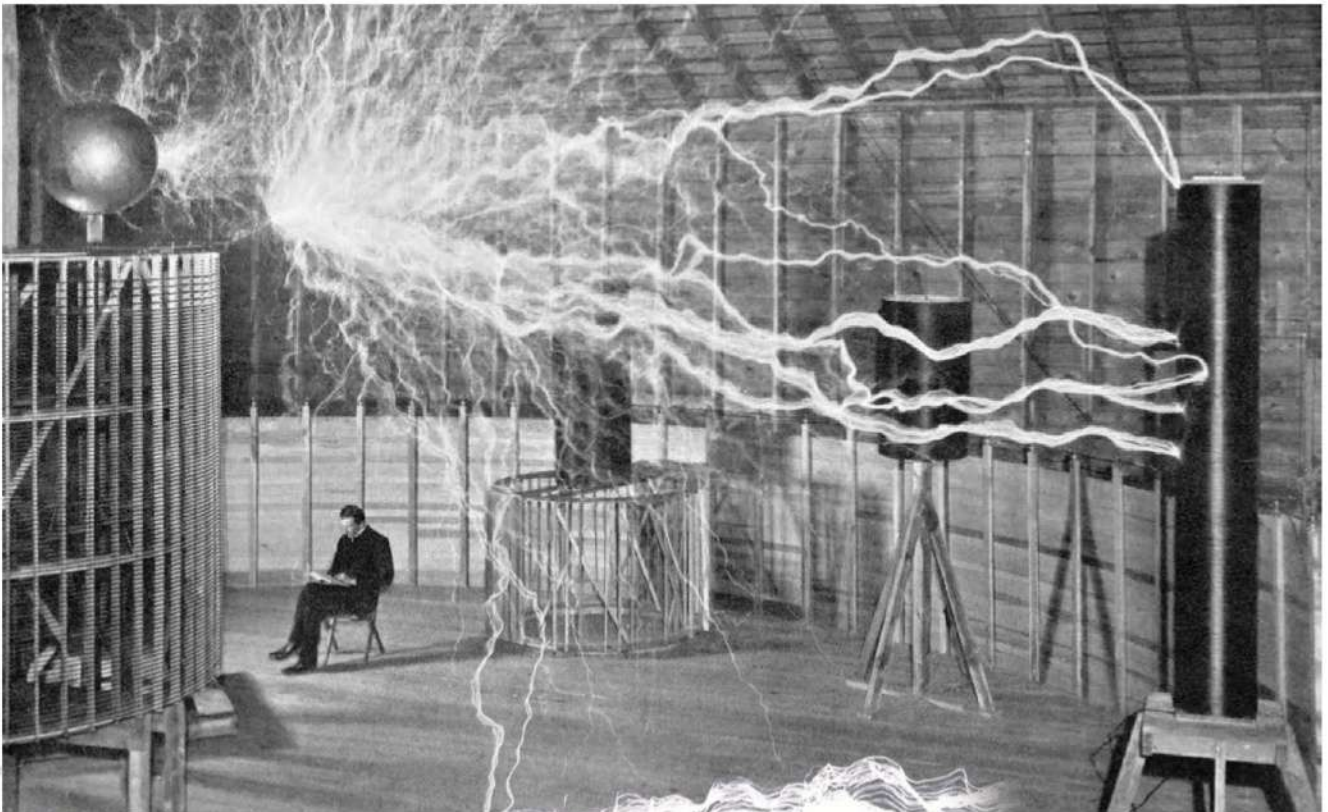
Around this time, Tesla hit upon two ideas that were to dominate his thinking from then on: the first was the transmission of electric power without wires; the second was wireless transmission of information (radio). In 1889, Tesla began experimenting with very high-voltage, high-frequency AC (current that oscillates thousands of times every second). Around 1891, he invented the Tesla coil: a kind of transformer that can produce very high voltages. Initially designed to provide wireless power to lights, it played an important role in the development of radio, television and X-ray technology. Meanwhile, Tesla continued his

War of currents

Nikola Tesla's most important achievement is his design of the power distribution system that has become the standard way of delivering electrical power from generator to consumer. Based on alternating currents, it superseded Thomas Edison's direct current system.

In 1893, the superiority of Tesla's AC system became apparent when the Westinghouse Electrical Company provided impressive electrification of the Chicago World's Fair. That year, Tesla had the chance to fulfil a childhood dream: to harness the power of the Niagara Falls. He and Westinghouse won the contract to build a power plant there, and their success when the first electricity flowed in 1896 bolstered the cause of AC power systems. In the following years, Edison mounted a bitter publicity campaign denouncing AC as dangerous, even going so far as orchestrating public electrocutions of animals and being involved in the development of the first electric chair (which was AC). Despite the campaign, the advantages of Tesla's system guaranteed its success.

“Tesla's system won out, and his AC motor has driven the wheels of industry ever since”



research into wireless broadcasting. Several other inventors were working on the same idea, but Tesla's mastery of high-frequency electricity put him ahead. In 1898, he designed and built the first remotely controlled vehicle: a boat, which he demonstrated to an amazed crowd in Madison Square Garden, New York.

In 1901, on Long Island, New York, work began on Wardencliff Tower, a hugely ambitious project Tesla hoped would demonstrate the potential for transmitting energy and information worldwide. Even as work was beginning on Tesla's tower, the Italian inventor Guglielmo Marconi (1874–1937) transmitted a radio signal across the Atlantic Ocean. The US Patent Office awarded priority in the invention of radio to Marconi. In 1905, funding for Tesla's project dried up, and the project was shut down.

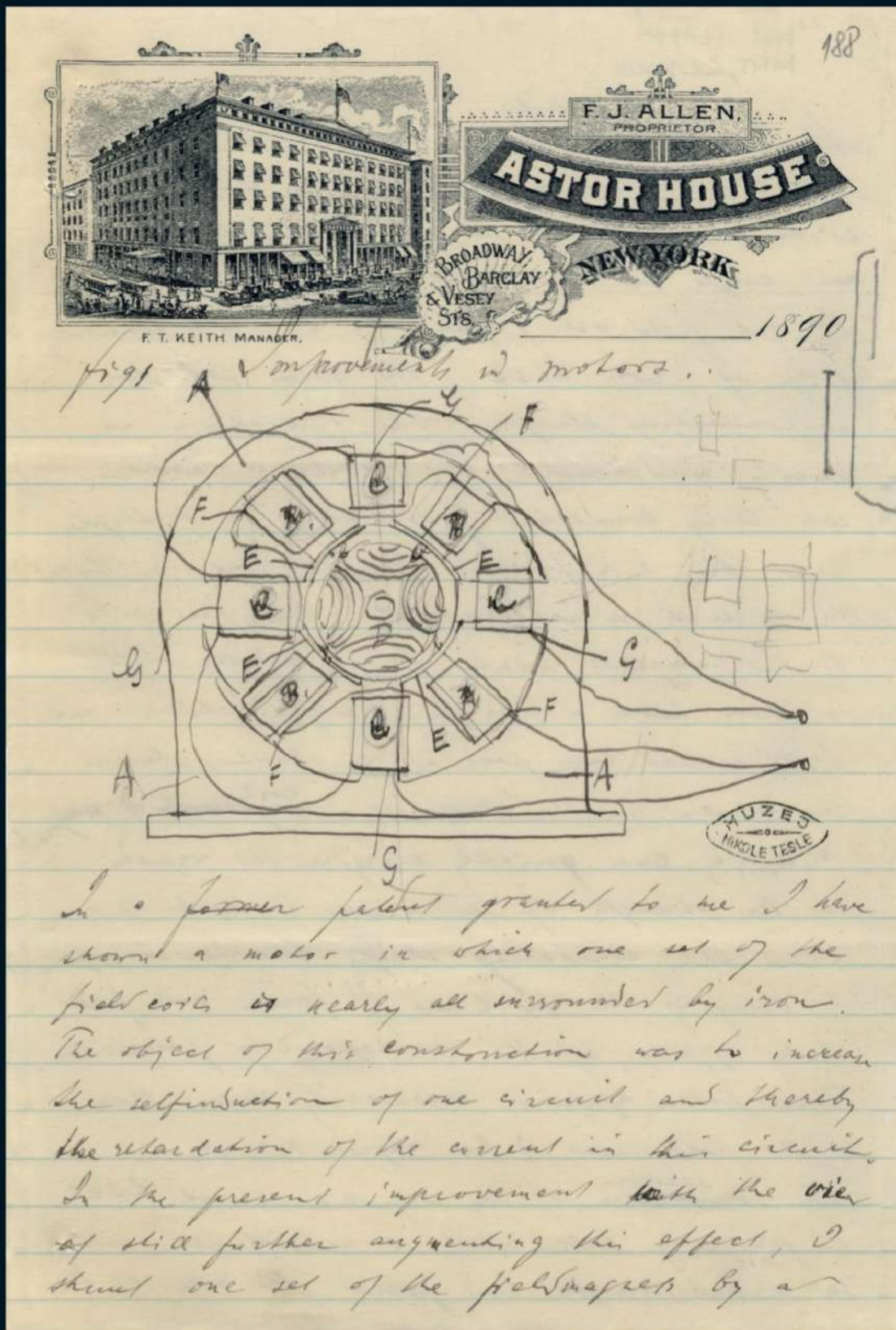
His patents lapsed, and with no financial backing, Tesla declared himself bankrupt in 1916 and spent the rest of his life in relative poverty and increasing obscurity. A few months after his death, however, the US Supreme Court overturned the earlier decision, and named Tesla as the real inventor of radio.

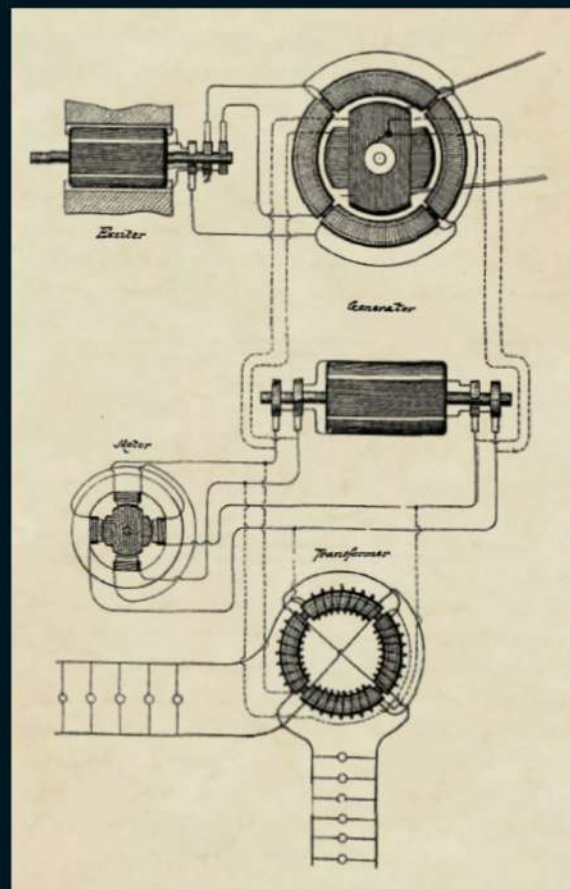
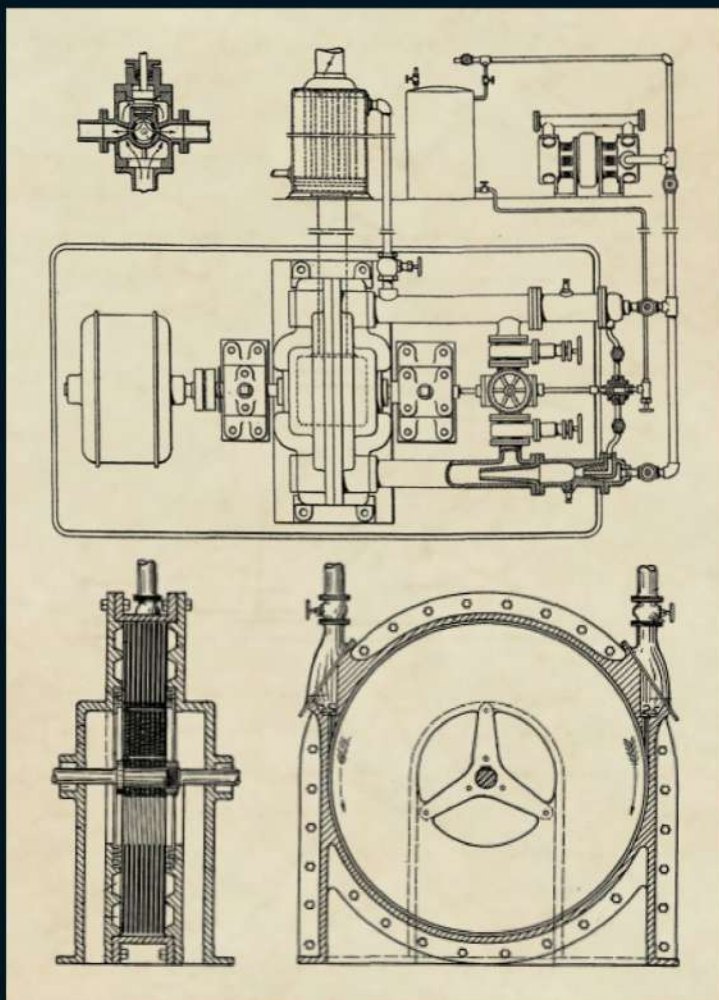
Above: Tesla in his Colorado Springs laboratory. To the left is his 'magnifying transmitter', which could produce millions of volts. The meandering sparks stretch about 7 metres (23 feet) across the laboratory. The photograph was probably a double exposure – with Tesla in one and the sparks in another.

Left: Sparks of 'artificial lightning' fly from a large tesla coil, Nemesis, built by the Tesla Coil Builders Association, in the USA. Nemesis runs on mains voltage (110 volts in the USA), but produces more than a million volts.



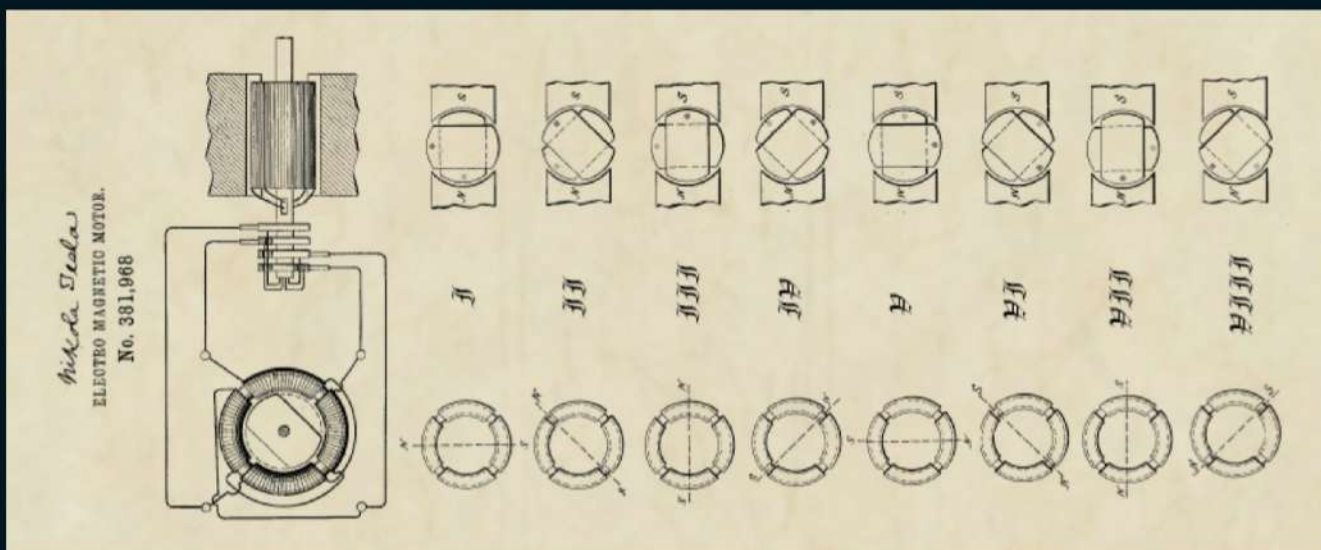
Right: Tesla's drawing and notes for improvements to his alternating current induction motor, on hotel notepaper (Tesla lived in luxurious hotels for much of his life in the USA). These notes relate to US patent 433,701, for which Tesla applied on 26 March 1890.





Left: Tesla's bladeless turbine—the Tesla turbine, Tesla's 100th American patent.

Above: Nikola Tesla's AC dynamo-electric machine (Electric generator) used to generate AC which is used to transport electricity across great distances.



Above: A rotating magnetic field is a magnetic field which periodically changes direction. This is a key principle to the operation of alternating-current motor. In 1882, Nikola Tesla identified the concept of the rotating magnetic field. In 1888, Tesla gained U.S. Patent 381,968 for his work.



Auguste and Louis Lumière

(19 October 1862–10 April 1954 and
5 October 1864–6 June 1948)

While no single person can be credited with inventing moving pictures, two French brothers – Auguste and Louis Lumière – stand out for their foresight and their important contributions. Using a film camera-projector that they designed, they put on some of the earliest public film screenings and helped to define cinema.

Auguste and Louis Lumière were born in Besançon, France, where their father had a photographic studio. In 1870, they moved to Lyon, and their father opened a small factory that made photographic plates. In 1882, Auguste and Louis helped to bring the factory back from the brink of financial collapse by mechanizing the production of the plates, and selling a new type of plate that Louis had invented the previous year. The firm moved to a larger factory in Montplaisir, on the outskirts of Lyon, where it employed 300 people.

In 1894, the brothers' father attended a demonstration of the Kinetoscope, a moving

Auguste (looking down the
microscope) and Louis
Lumière in Auguste's
laboratory, 1930s.





Above: The Lumières' film of Queen Victoria's Diamond Jubilee procession in London, 1897. Its circular sprocket holes are characteristic of the Lumières' system. Other early filmmakers used 35mm film with rectangular Edison perforations.

Top Right: The Lumière Cinématographe – an all-in-one film camera, printer and projector. For shooting, only the camera is needed; the wooden box. The magic-lantern lamphouse – the large black box – contains the light source for projection.



picture peep-show device developed at the laboratory of American inventor Thomas Edison (1847–1931). The Kinetoscope was not a projector – only one person could watch a film at a time – but it was fast becoming popular entertainment. Antoine saw a commercial opportunity and, returning to Lyon, suggested his sons work on producing an apparatus that could record and play back moving images.

Louis, the more technically minded of the two brothers, designed the camera-projector, while Auguste designed the housing for the light source.

Louis developed the film transport mechanism, inspired by a similar device in sewing machines, which allowed each frame of the film to stop momentarily behind the lens.

The Lumière brothers patented their camera-projector, the Cinématographe, in February 1895. Louis shot their first film, which was called *La Sortie de l'Usine Lumière à Lyon* (*Workers Leaving the Lumière Factory in Lyon*), and the pair showed the film to the Société d'Encouragement de l'Industrie Nationale, in Paris in March 1895, the first public screening of a film.



Pioneers of motion pictures

The Lumière brothers pioneered cinema, but weren't the first to make moving-picture films. Many were experimenting with moving pictures several years before them. One of the first people to capture realistic movement on film was French inventor Louis Le Prince (1841–1890). Le Prince made his first successful film in October 1888. This was a sequence shot in his father-in-law's garden in Leeds, England, showing his son, his in-laws and a family friend.

The Lumières were not the first to project films to a paying audience, either. Projection and a paying audience form the definition of cinema. That honour of the first cinema performance goes to American brothers Grey and Otway Latham, who projected their films in New York in May 1895. But the 'projector' they were using was simply a modified Edison Kinetoscope, and the results were not very good.



“They refused to sell their devices to anyone except through their own agents”

After several other screenings in France, their father arranged for the first performances to a paying audience. Ten films were shown 20 times a day. The opening night, at the Salon Indien – the empty basement of the Grand Café in Paris – was in December 1895. Auguste and Louis did not attend the first day, because they felt the technology still needed more work.

Great success

After a slow start, the shows became a great success. In 1896, the Lumière brothers sent their agents abroad, demonstrating their Cinématographe and arousing great interest. They also ordered 200 or so of the camera-projectors to be constructed, and opened agencies in several countries to sell them. The Lumière franchise was very successful, but they refused to sell their devices to anyone except through their own agents.

By 1897, Thomas Edison had developed a system of sprocket holes that was incompatible with the

Cinématographe and that was quickly becoming the standard in a rapidly developing industry. By 1905, Edison's system would predominate and the Lumière brothers would leave the film business altogether.

Auguste's interests turned to chemistry and medicine. In 1910, he founded a laboratory in Lyon, where his 150 staff carried out research into cancer and other diseases. Auguste invented a dressing for burns, called tulle gras, which is still used today, and pioneered the use of film in surgery, which helped generations of medical students. Meanwhile, in the early 1900s, Louis demonstrated a sequence shot on a new, wider-format film, and later experimented with panoramic and stereoscopic (3-D) films.

In 1904, the Lumière brothers perfected a colour photography system known as Autochrome; they had been working on colour photography ever since the early 1890s. Autochrome was the most important colour photographic process until colour film became available in the 1930s.

Above: Colour photograph, c.1910, taken with the Lumières' Autochrome system. When shooting, a glass slide coated with randomly scattered red-, green- and blue-pigmented starch grains was held in front of the (black and white) film; the same slide was required for viewing.

Top Left: One frame from the Lumière Brothers' first film, *La Sortie de l'Usine Lumière à Lyon*, 1895. The film was shot at 16 frames per second and, at that rate, it runs for just under 50 seconds. It features most of the nearly 300 workers – mostly women – walking or cycling out of the factory yard.



Wilbur and Orville Wright

(16 April 1867–30 May 1912
& 19 August 1871–30 January 1948)

At the dawn of the 20th century, two brothers from a small town in the USA – Wilbur and Orville Wright – became the first to achieve sustained, powered flight.

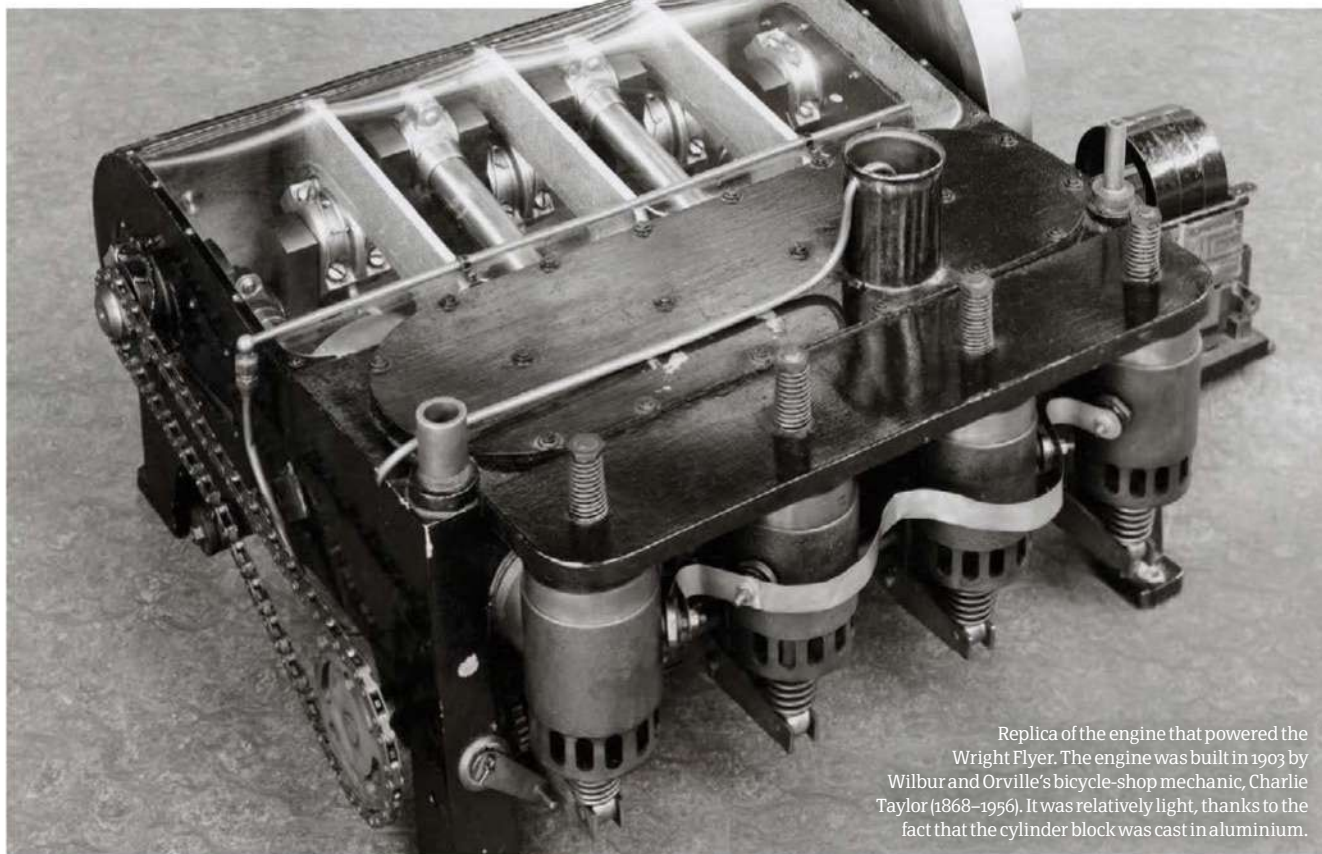
The key to their success was the combination of their inventive, mechanical skill with the application of scientific principles to flight. Moreover, they learned to become pilots in a gradual, thoughtful way, rather than risking everything on one short trial, like so many other pioneers.

Wilbur (seen right) and Orville (left) Wright grew up in Dayton, Ohio, in a family with seven children (although two died in childhood). They were mechanically-minded from an early age: in 1886, they built their own lathe; in 1888, they built a printing press, which they used to produce their own local paper; and in 1892, they opened a bicycle repair shop. They used the profits of the shop to finance their efforts in aviation.



First successful flight of the Wright Flyer, by the Wright brothers. It travelled 120 ft (36.6 m) in 12 seconds at 10.35 am at Kill Devil Hills, North Carolina. Orville Wright was at the controls. Wilbur Wright ran alongside to balance the machine, and just released his hold on the forward upright of the right wing in the photo.





Replica of the engine that powered the Wright Flyer. The engine was built in 1903 by Wilbur and Orville's bicycle-shop mechanic, Charlie Taylor (1868–1956). It was relatively light, thanks to the fact that the cylinder block was cast in aluminium.

“The brothers decided to build full-size, piloted gliders”

The dream of human flight stretches back to antiquity, but it was only in the late 18th century that people finally made it into the air, by courtesy of 'lighter-than-air' balloons. In the 19th century, scientists and inventors began giving serious consideration to the problem of 'heavier-than-air' flight. Providing power was problematic, since steam engines were large and very heavy. During the 1880s and 1890s people flew in unpowered gliders and kites. In 1899, the Wright brothers built a large box kite. Wilbur hit on the idea that by twisting the box shape, it would be possible to change the airflow over the wings and make the kite bank and turn. He called this effect 'wing warping', and it would be crucial to the brothers' later success.

After the kite performed well, the brothers decided to build full-size, piloted gliders, with wing warping effected via control cables. They

constructed their first glider in 1900, and also added a front 'wing' called an elevator, for pitch control. They chose the open area on the coast, near the tiny fishing village of Kitty Hawk in North Carolina, for its steady on-shore winds. First they flew the glider tethered like a kite, moving to the nearby Kill Devil Hills for actual flights. During 1901 and 1902, Wilbur and Orville built and tested two more gliders, and they also carried out hundreds of experiments in a homemade wind tunnel in their bicycle shop back in Dayton. By analysis and practical trials the brothers became the first to realize that controlling an aircraft required the banking control (wing warping or aileron), rudder and elevator all to be used continuously in combination. They were now ready to make a powered version of their flying machine. For driving the aeroplane, they designed and built large wooden propellers and, with a colleague in the bicycle shop, made a purpose-built, lightweight, powerful engine.

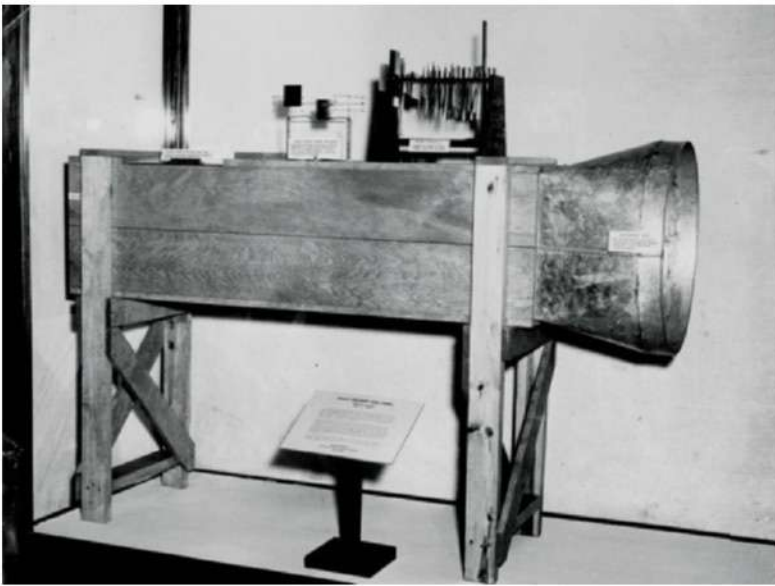
Testing their ideas

In December 1903, at Kill Devil Hills, the Wright

Otto Lilienthal (1848-1896)

It was Wilbur who was first struck by the desire to build a powered flying machine, after reading a magazine article about Otto Lilienthal, a German gliding pioneer. Lilienthal realized that to develop successful flying machines, any inventor needed to understand the scientific principles behind flight but also needed first-hand experience of flying. The Wright brothers took the same approach, and paid tribute to Lilienthal as their inspiration.

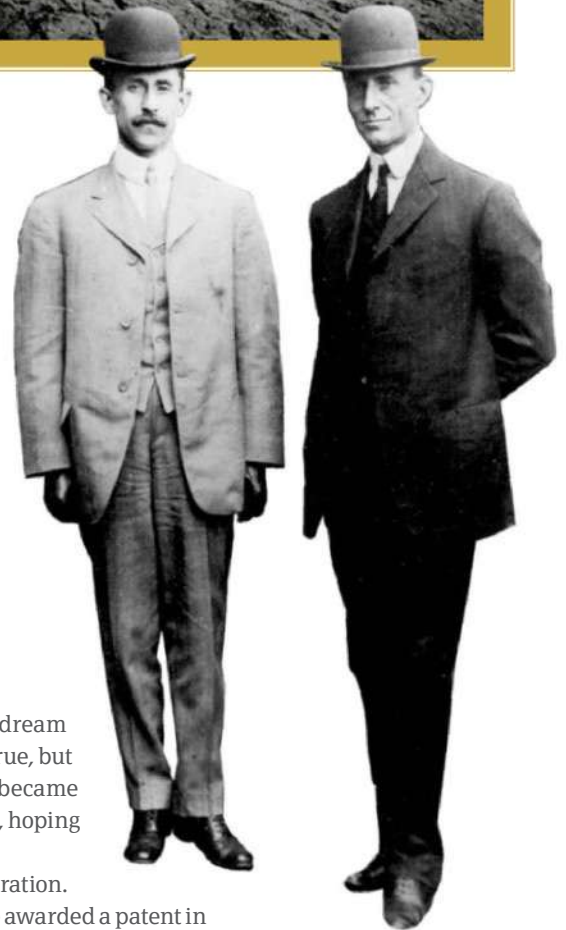
Lilienthal began his quest to fly by studying birds, and then carried out a huge amount of research into aerodynamics. In the 1890s, he made nearly 2,000 flights, mostly from an artificial hill he built near Berlin, in gliders he had designed and constructed. During what was to be his last flight, a gust of wind made him stall at an altitude of 15 metres (50 feet). He crashed to the ground and died the next day from his injuries. According to legend, his last words were: "Sacrifices must be made."



brothers were ready to put all their ideas, experiments and calculations to the test. The first successful flights took place on December 17. There were four flights that day, two by each brother. The first, with Orville piloting, lasted just 12 seconds and covered 37 metres (120 feet). The final flight of the day, with Wilbur as pilot, lasted 59 seconds and covered 260 metres (852 feet). By 1905, the Wright brothers' flying machines were routinely staying in the air for several minutes at a time, taking off, landing, and manoeuvring with ease. At first, the world was slow to recognize the Wrights' achievement, despite the fact that there were several witnesses on the day. This was partly because the media and the public were unwilling

to believe that the age-old dream of flight had finally come true, but also because the brothers became secretive about their work, hoping to sell their invention to a government or large corporation.

Wilbur and Orville were awarded a patent in 1906 for a 'Flying Machine'. Three years later they founded The Wright Company. Wilbur died within three years, from typhoid. Orville became a long-time advisor to the US Government's National Advisory Committee for Aeronautics, and was able to appreciate the incredibly rapid developments in aviation that took place within a few decades of those first flights.



Above Left: The Wright brothers' wind tunnel. They used it to test wing designs to compile the first accurate tables of lift and drag forces on wings and understand how the lift force moves back or forward as the wing tilts, affecting control.

Wilbur Wright
Orville Wright

Established in 1892



1127 West Third Street

DAYTON, OHIO, Dec 28, 1903.

Dear Mr. Chanute,

Your telegram of congratulation and the Christmas remembrances have reached us, and, of course, we are deeply gratified at your kindness.

The axles for which we were waiting when you visited us, did not arrive for one whole week after your departure. We spent part of this time in installing a new system of operating the wing tips and rear rudders, as the old system did not seem quite satisfactory. We then spent three days putting the axles in place again, and giving the machine the final touches. When ready for trial a three days storm kept us penned up so that another week was lost. We however made some indoor tests of the thrust of the propellers and found that we would have a plenty of power as the transmission only cost 5 or 10 percent apparently, instead of the thirty percent you had estimated. The thrust of the screw came within three or four pounds of our calculations of what it would do in a fixed position. But as we were concluding these experiments a peculiar feeling led to an in-

Above: A letter dated 28 December 1903 from Wilbur Wright to French-born American aviation pioneer Octave Chanute (1832-1910), describing in detail the Wright brothers' achievements earlier that month.

Wilbur Wright
Orville Wright

2

Established in 1892



Wright Cycle Company

1127 West Third Street

DAYTON, OHIO,-----

investigation which revealed the fact that one of the axles was giving way. Accordingly we removed both of them and Orville went home to make new ones. He was gone two weeks more, so that by the time every thing was ready again, five weeks had elapsed since the trouble with the axles began. We accordingly determined to try the machine at the earliest opportunity instead of waiting for the conditions we desired. So on the 14th inst although the wind was only 2 to 3 metres a second, thus making it necessary to use the hill in starting, we got the machine out and made the first trial. It rose from the track and soon reached a point as high as the starting point but as this was done too suddenly it lost speed somewhat so that it was no longer fully supported. In turning down to regain speed the rudder was moved too far, and the machine darted down and touched ground before it could be turned up again. The time was only $3\frac{1}{2}$ seconds and the distance a little more than a hundred feet. The landing was made with the propellers still going, and with the machine sidling somewhat. The lower struts of the front rudder frame sunk into the sand and as it was braced only at the ends the

Wilbur Wright
Orville Wright

3

Established in 1892



Wright Cycle Company

1127 West Third Street

DAYTON, OHIO.

side pressure of the sand broke one of them, and it in turn twisted off one of the upper struts. The main machine and the skids under it, of which we were so fearful, stood the test perfectly, although the landing was made at a speed of more than twenty miles an hour.

Our next flights were on Thursday, Dec. 17th, on which occasion the flights were all made from a level spot about 200 feet west of our buildings. The wind had a velocity of 24 to 27 miles an hour according to the Pitty Hawk anemometer which was almost directly to windward of us, but our measurement made with the English anemometer at a height of 4 ft from ground was only 20½ miles. The conditions were very unfavorable as we had a cold gusty ~~on~~ north wind blowing almost a gale. Nevertheless as we had set our minds on being home by Christmas, we determined to go ahead. Four flights were made, the first lasting about 12 seconds and the last

Wilbur Wright
Orville Wright

7

Established in 1892



DAYTON, OHIO,

59 seconds. The "Junction Railroad" worked perfectly and a good start was obtained every time. The machine would run along the tracks about 40 ft propelled by the screws alone, as we did not feel it safe to ~~do~~ have strangers touch the machine. It would then rise and fly directly against the wind at a speed of about 10 miles an hour. The first flight was of about 12 seconds duration and the last 59 seconds. The controlling mechanisms operated more powerfully than in our old machine so that we nearly always turned the rudders more than was really necessary and thus kept up a somewhat undulating course especially in the first flights. Under the prevailing conditions we did not feel it safe to rise far from the ground and this was the cause of our flights being no longer than they were, for we did not have sufficient room to maneuver in such a gusty gale.

Wilbur Wright
Orville Wright

5.

Established in 1892



1127 West Third Street

DAYTON, OHIO,-----

Consequently we were frequently on the point of touching the ground and once scratched it deeply but rose again and continued the flight. Those who understand the real significance of the conditions under which we worked will be surprised rather at the length than the shortness of the flights made with an unfamiliar machine ~~after~~ less than one minutes practice. The machine possesses greater capacity of being controlled than any of our former machines.

One of the most gratifying features of the trials was the fact that all our calculations were shown to have worked out with absolute exactness so far as we can see, though we have not yet made our final computations on the performance of the machine.

Orville and I alternated in the flights according to our usual custom.

With wishes for a Happy New Year
Yours truly
Wilbur Wright





54.

far on the other. As a result the machine ^{to about 10 ft} would rise suddenly and then as suddenly, on turning the rudder, dart for the ground. A sudden dart when out about 100 feet from the end of the tracks ended the flight. Time about 12 seconds (not known exactly as watch was not promptly stopped). The second flight device for throwing off the engine was broken, and the skid under the rudder cracked. After repairs, at 20 min after 11 o'clock Will made the second trial. The course was about like mine, up and down but a little longer over the ground though about the same in time. Dist not measured but about 175 ft. Wind speed not quite so strong. With the aid of the station men present, we picked the machine up and carried it back to the starting ways. At about 20

minutes till 12 o'clock ⁵⁵ I made the third trial, ~~Will~~ ^{out} about the same distance as Will's, I met with a strong gust from the left which raised the left wing and sidled the machine off to the right in a lively manner. I immediately turned the rudder to bring the machine down and then worked the end control. Much to our surprise, on reaching the ground the left wing struck first, showing the lateral control of this machine much more effective than on any of our former ones. At the time of its sidling it had raised to a height of probably 12 to 14 feet. At just 12 o'clock Will started on the fourth and last trip. The machine started off with its ups and downs as it had before, but by the time he had gone three or four hundred feet he had it under much

Above: Orville Wright's diary from 1903, manuscript photograph. Entry notes the first successful airplane flight.



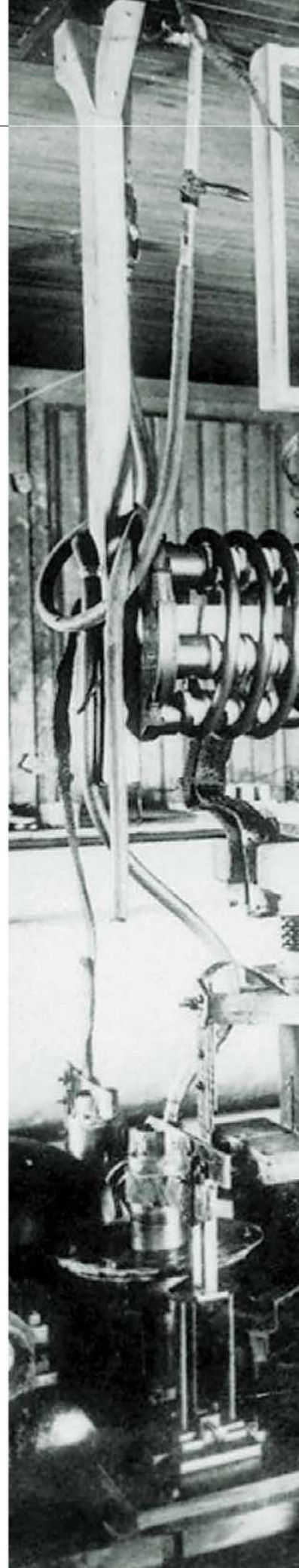
Guglielmo Marconi

(25 April 1874–20 July 1937)

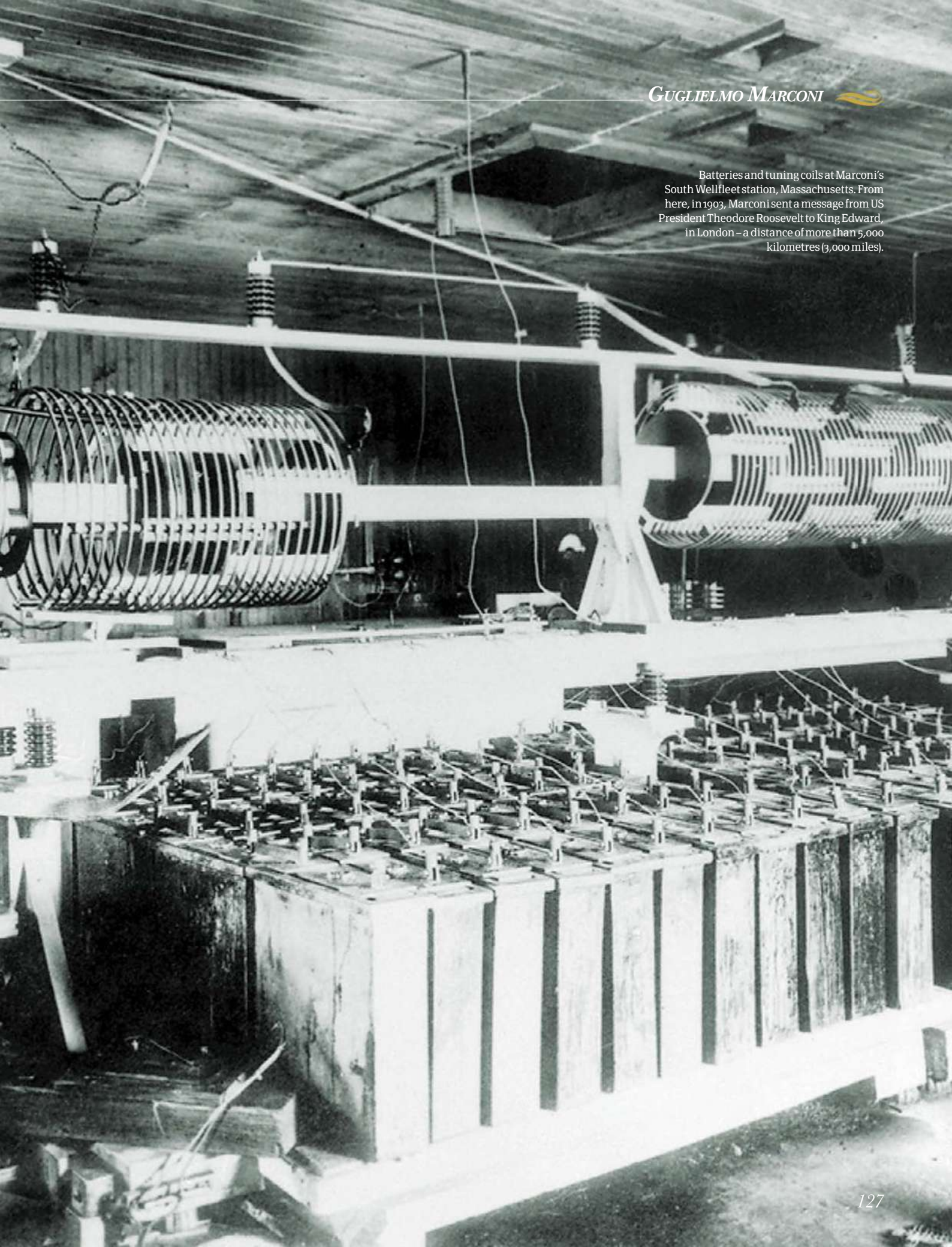
The early history of radio is rather complex, and credit is due to dozens of important pioneers. One of the most important and successful was Italian inventor Guglielmo Marconi, who helped bring radio into everyday use.

Guglielmo Marconi was born in Bologna, Italy to an Italian father and an Irish mother. From an early age, he took an interest in science and was particularly interested in electricity. In late 1894, Marconi became aware of the experiments of the German physicist Heinrich Hertz (1857–1894), who had succeeded in proving the existence of radio waves during the late 1880s.

Hertz produced radio waves by sending a rapidly alternating current up and down a vertical antenna, and detected the waves up to 20 metres (65 feet) away. Marconi also read about a demonstration that English physicist Oliver Lodge (1851–1940) had recently performed. Lodge sent Morse-code messages wirelessly, using the



Batteries and tuning coils at Marconi's South Wellfleet station, Massachusetts. From here, in 1903, Marconi sent a message from US President Theodore Roosevelt to King Edward, in London – a distance of more than 5,000 kilometres (3,000 miles).



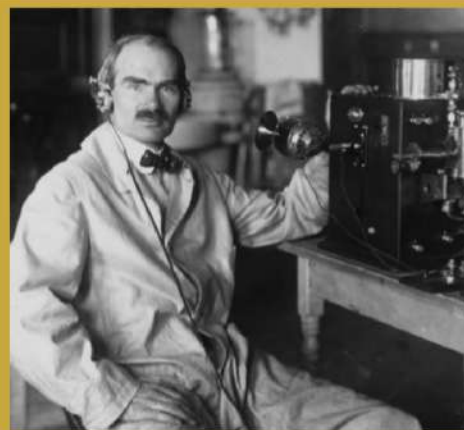


Above: Sailors on board ship, reading a 'marconigram', in the early 1900s. Just as a telegram was a physical record of a Morse code message sent via telegraph wires, a marconigram was a record – on paper tape – of Morse-code message received wirelessly via radio.

'Hertzian' waves. At the time, telegraph messages in Morse code could only be sent as electric pulses along wires, and Marconi was excited at the prospect of 'wireless telegraphy'.

Marconi decided to carry out experiments of his own, with the aim of making wireless telegraphy a useful, practical technology. He set up a laboratory in the attic room of his family home, and assembled the necessary components. He was soon sending and receiving Morse code wirelessly over increasingly large distances: first across the room, then down a corridor, then outside, across fields. In the summer of 1895, Marconi transmitted a message over nearly 2 kilometres (1.2 miles), and in 1896 patented his system. On being refused funding by the Italian government, he decided to travel to Britain to seek interest there.

“He was soon sending and receiving Morse code wirelessly over increasingly large distances”



Lee De Forest (1873–1961)

In the early 1900s, radio communication could only be made using wireless telegraphy – sending Morse-code messages as on-and-off pulses of radio waves. That changed with the introduction of audio broadcasting; regular broadcasts began in 1920. One of the most important technologies involved in the development of audio broadcasting was the Audion, invented in 1906 by American electronics engineer Lee de Forest.

The Audion was an early example of a 'valve' that found myriad uses in the developing field of electronics. In radio and television broadcasting, it enabled the construction of all-electronic 'oscillators', which produced radio waves of any frequency to order. From the 1920s until the 1960s, radio and TV sets used valves for amplification. Eventually, they were replaced by the smaller, less power-hungry transistor, invented in 1947.

Following a series of impressive demonstrations during 1897, Marconi garnered the support of the Post Office, which was in charge of Britain's telegraph system at the time. In that year, he formed the Wireless Telegraph & Signal Company to expand his work. In the following few years, he sent messages over ever greater distances and, notably, between ships and from ship to shore. In 1900, Marconi decided to try extending the range of his transmissions yet further: across the Atlantic Ocean. In 1901, he created a worldwide sensation when he announced the successful transmission of a Morse code letter 'S' (three short bursts of radio) from Poldhu, in Cornwall, England to St John's, Newfoundland (then a British colony, now in Canada). After suggestions that he had faked the

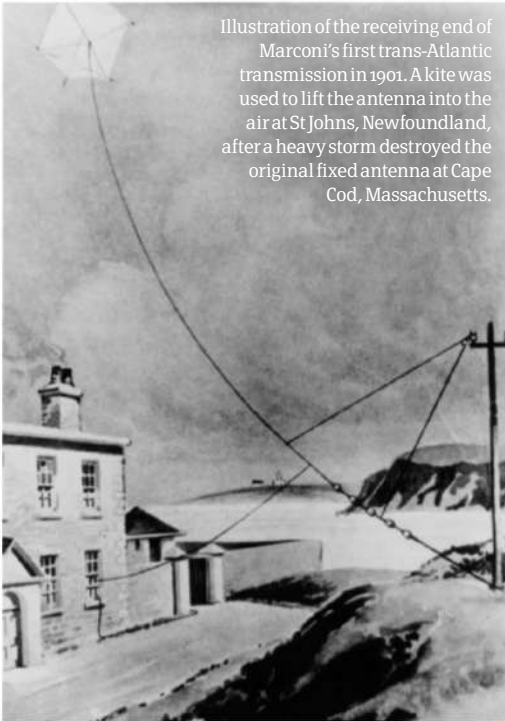


Illustration of the receiving end of Marconi's first trans-Atlantic transmission in 1901. A kite was used to lift the antenna into the air at St Johns, Newfoundland, after a heavy storm destroyed the original fixed antenna at Cape Cod, Massachusetts.

transmission, he carried out another, carefully monitored experiment the following year. Aboard a ship close to the Canadian coast, he received signals from Cornwall more than 3,200 kilometres (2,000 miles) away.

Improvements

During the years that followed, Marconi made several important improvements to his system of radio transmission, and in 1907 he instigated the first commercial trans-Atlantic radio service. He found fame again when the British ocean liner RMS *Titanic* hit an iceberg and sank in 1912. A Marconi-radio operator aboard the sinking ship managed to broadcast radio distress signals and summon help from nearby ships.

During the 1920s, Marconi experimented with much higher-frequency radio waves. These 'short waves' can be focused by a curved reflector behind the transmitter, like the parabolic dishes used to receive satellite communications. This arrangement made radio more efficient and less power-hungry, since the waves were concentrated into a beam and not radiating in all directions. By this time, radio operators, including Marconi, were transmitting not only Morse code, but also speech, music and audio signals. In 1931, he experimented with even



higher-frequency, shorter-wavelength radio waves – microwaves – and a year later, he installed a beamed, microwave radio-telephone system between the Vatican and the Pope's summer residence. Much of today's telecommunications infrastructure is built on microwave beams like this.

Marconi did not invent radio, but he did make several important improvements to it, and his determination to turn a complicated laboratory curiosity into something useful and commercially successful helped make the world feel a bit smaller. In 1909, he received the Nobel Prize for Physics, for his contributions to wireless telegraphy, and in 1930, he became president of the Royal Italian Academy.

Above: 'Marconiphone' amplifier from around 1925, with valves – the developments of de Forest's Audion (see box). Marconi formed the Marconiphone Company in 1922, to manufacture radios sets for domestic use as well as amplifiers like this one, which made it possible to listen without headphones.



Carl Bosch

(27 August 1874–26 April 1940)

There is one 20th-century invention that arguably changed the world more profoundly than any other. It is not a machine or a device, but an industrial process. The manufacture of ammonia, perfected by German chemist Carl Bosch, enabled the production of fertilizers and explosives on a completely unprecedented scale, resulting in a meteoric rise in population and unlimited explosive capacity in two world wars.

Carl Bosch was born in Cologne, Germany. He studied mechanical engineering and metallurgy at Charlottenburg Technical University. In 1896, he began studying chemistry, at the University of Leipzig. Three years later, Bosch joined Germany's most successful chemical company, in Ludwigshafen. At the time, the company's name was Badische Anilin- & Soda-Fabrik; nowadays, the name is simply BASF.

At first, Bosch worked on synthetic dyes, but in 1905 he turned his attention to a major question

The Board of Directors of IG-Farben, Germany. In front (left) Carl Bosch. Hermann Groeber, 1926, Oil on canvas.





Fertilizers

Carl Bosch made it possible to produce huge quantities of ammonia, much of which is made into nitrogen-rich ammonium nitrate (NH_4NO_3) fertilizer. Careful estimates suggest that synthetic fertilizers feed about half of the world's population. Plants rely upon nitrogen compounds for building proteins and DNA (deoxyribonucleic acid). In nature, nitrates come from decaying plant and animal matter and from certain bacteria, which fix nitrogen from the air.

Bosch's lasting legacy is double-edged, however. Artificial fertilizers saved millions from starvation, but the huge increases in population they allowed, from nearly 1.8 billion in 1910 to nearly 7 billion a century later, have put a strain on the world's resources. Their manufacture accounts for about one per cent of the world's total energy consumption and their use causes pollution; agricultural run-off creates 'harmful algal blooms' in lakes and estuaries due to the extra nitrogen.



Above: Synthetic ammonia fertilizer factory, 1920s. Before Bosch developed his industrial process, only bacteria, living in the soil or in water, could 'fix' nitrogen from the air in these quantities. The production of synthetic nitrogen-based fertilizers enabled the world to avoid mass starvation.

of the day: how to 'fix' atmospheric nitrogen into chemical compounds. This seemingly esoteric issue was actually of immense global significance. Scientists in the 19th century had realized that nitrogen-rich compounds made very effective fertilizers. In particular, huge deposits of guano (fossilized bird excrement) and saltpetre (potassium nitrate, KNO_3) had helped to sustain an ever-expanding world population. In 1898, English chemist William Crookes (1832–1919) delivered a lecture to the British Association entitled 'The Wheat Problem', in which he noted that these deposits were dwindling. Crookes suggested that the world could face major famines by the 1920s. In addition, nitrogen compounds were an essential ingredient in explosives. In the early years of the



Above: German chemist Fritz Haber, photographed in 1918, the year he won the Nobel Prize for Chemistry. Haber developed the reaction that produces ammonia from nitrogen and hydrogen gases, which Bosch scaled up in 1910; the resulting technique is today called the Haber-Bosch Process.

20th century, a growing threat of war led to further increases in the demand for nitrogen compounds.

The role of nitrogen

As an element, nitrogen is notoriously unreactive. That is why it makes up nearly 80 per cent of the atmosphere. From the 1890s, chemists had tried in vain to find an efficient, high-yield process to fix nitrogen from the air to make fertilizers and explosives. Then, in 1905, German chemist Fritz Haber (1868–1934) reported that he had produced small amounts of ammonia from nitrogen gas (N_2) and hydrogen gas (H_2). Haber's process required high temperature, high pressure and a catalyst – a chemical that speeds up a reaction, while remaining unchanged, or a



Above: A German World War I biplane dropping a bomb. The manufacture of explosives depended upon a plentiful source of nitrogen-rich compounds. Bosch's process for the manufacture of ammonia helped Germany meet the demand and sustain its war effort.



Heavy use of artificial fertilizers causes dead zones, like this one in the Gulf of Mexico. They form in lakes and coastal seas as agricultural run-off finds its way into water courses, causing a proliferation of algae, which starve other organisms of oxygen.

chemical that lowers the energy needed for a reaction to take place, therefore speeding it up. Haber was working under contract to BASF and, by 1909, he had produced an impressive yield of ammonia in his laboratory. In that year, BASF gave Bosch the task of scaling up Haber's reaction for use on an industrial scale.

Bosch developed a reaction vessel that could withstand the high temperatures and pressures that were necessary: a double-walled chamber that was safer and more efficient than Haber's system. He carried out nearly 20,000 experiments before he found a more suitable catalyst than the expensive osmium and uranium Haber had used. Bosch also worked out the best ways to obtain large quantities of hydrogen – by passing steam over red-hot coke – and nitrogen, from the air. He patented his results in 1910, and by 1911, BASF had begun producing ammonia in large quantities. The company opened the world's first dedicated ammonia plant, in Oppau, a suburb of Ludwigshafen, just two years later. The ammonia was used to make artificial fertilizers in huge quantities. When the First World War began in 1914, however, the German government was faced with a shortage of ammunition, and the output of the Oppau plant was used to produce explosives instead. Without the Haber-Bosch process, the war would probably not have lasted as long as it did; Britain had blockaded Germany's imports of saltpetre, which Germany had relied upon to make explosives.



Bosch's intensive work and his insight into chemistry and engineering helped to lay the foundations of large-scale, high-pressure processes – which, in turn, underpin much of the modern chemical industry. In 1931, he was awarded the Nobel Prize for Chemistry. Today, nearly 200 million tonnes of synthetic nitrogen fertilizers are produced worldwide every year – several tonnes every second – using the Haber-Bosch process.

Above: The world's first ammonia synthesis plant, at Oppau, near BASF's headquarters in Ludwigshafen, Germany. In its early years, the plant produced more than 7,000 tonnes of ammonia, made into 36,000 tonnes of ammonium sulphate.



Vladimir Zworykin

(30 July 1889–29 July 1982)

Television changed the way of life of hundreds of millions of people in the 20th century. But the history of this far-reaching invention is far from simple: dozens of inventive people contributed to its development. One of the most significant pioneers was Russian-born inventor Vladimir Zworykin, who also made important contributions to the development of the electron microscope.

Vladimir Zworykin was born in the town of Murom, in what was then the Russian Empire. As a child he spent time installing and repairing electric doorbells in the family-owned passenger steamships. In 1912, he obtained a degree in engineering from the Saint Petersburg Institute of Technology. At the Institute, one of Zworykin's professors, Boris Rosing (1869–1933) showed him a project he had been working on in secret. Rosing called it 'electric telescoping' – one of the early names for television; several other people in other countries were working on the same idea.





Vladimir Kosma Zworykin (1889-1982), a Westinghouse Electric and Manufacturing Company research engineer, is demonstrating his new cathode ray television set that can entertain large groups. Mildred Birt is the watcher. Broadcast images are projected on a mirror on the top of the cabinet making it possible for many to watch.



Below: Zworykin's night-vision device, the snooperscope, photographed in 1944. The snooperscope was sensitive to infrared radiation, which warm-blooded animals emit with greater intensity than non-living things, by virtue of their warm bodies. Zworykin's device helped soldiers in night-time conflicts in World War II.



Indeed, as early as 1908 the Scottish engineer AA Campbell Swinton (1863–1930) had published a letter in which he outlined his concept for 'distant electric vision' using the cathode-ray tube, invented in 1897 by German physicist Karl Ferdinand Braun (1850–1918). A cathode-ray tube is a glass tube, from which the air has been removed, in which a beam of electrons strikes a flat screen. The inside of the screen is coated with chemical compounds called phosphors, which

glow wherever electrons collide with them.

Electromagnets positioned around the tube control the direction of the beam, and the television signal fed to the magnets causes the beam to scan in horizontal lines across the screen. By scanning the whole screen in this way several times every second, while also varying the intensity of the electron beam, it is possible to display a moving image. Swinton never attempted to build the system he conceived, and while Rosing was a pioneer, his system was crude and unwieldy, and never worked.

Zworykin's system

In 1919, after the Bolshevik Revolution



Above: Combined electronic television set and radio receiver, 1938, made by British company Pye. The 23-centimetre (9-inch) cathode ray tube (CRT) screen is a descendant of Zworykin's kinescope.

during the Russian Civil War, Zworykin emigrated to the USA. Within a year he had begun working at the Westinghouse Electric and Manufacturing Company in Pittsburgh. In 1923, after spending a considerable amount of his spare time working on television, he applied for a patent. Zworykin's system used one cathode-ray tube to display pictures and another one in the camera. Inside his television camera, light fell on the screen of the cathode-ray tube. Instead of phosphors, this screen was coated with light-sensitive dots made of potassium hydride. An electron beam scanned the screen, as in the picture tube, and each light-sensitive dot produced a signal that depended on the brightness of the image at that point.

After submitting an improved patent application in 1925, Zworykin demonstrated his television system to his employers at Westinghouse. The images were rather dim



Television pioneers

For much of the 1930s, Vladimir Zworykin was embroiled in a lengthy patent battle between the Radio Corporation of America (RCA) and another television pioneer, American inventor Philo T Farnsworth (1906–1971). Farnsworth won the battle – at great cost to RCA. Another important figure in developing electronic television was Hungarian inventor Kálmán Tihanyi (1897–1947), whose work was crucial in making Zworykin's Iconoscope camera work. There was another approach to television besides the all-electronic system: the 'electromechanical system'. In 1924, Scottish inventor John Logie Baird (1888–1946; shown far left, standing by the railings) transmitted the first-ever television pictures. The earliest photograph of a television picture (above) shows Baird's business partner. Instead of electron beams scanning the inside of a cathode ray tube, Baird's device used spinning discs with spiral holes to produce images. Electromechanical systems made some of the earliest television broadcasts – but electronic television won out in the end.

and stationary, and his employers were not at all impressed.

He received a more favourable response when he showed it to the Radio Corporation of America (RCA) in 1929. Zworykin's camera, later dubbed the Iconoscope, would become the standard way of producing television pictures. Zworykin developed the technology even further at the RCA. In 1939, the company demonstrated it at the New York World's Fair and, in 1941, the RCA began regular commercial television broadcasts in the USA.

Zworykin's work on the electron microscope stemmed from his wealth of experience working with images and electrons. In 1938, he employed



“In 1940, Zworykin's team achieved the first magnification greater than 100,000x”

Canadian electronic engineer James Hillier (1915–2007) and worked with him to improve on the electron microscope, which had been invented in the early 1930s in Germany. In particular, the team developed the scanning electron microscope, in which a beam of electrons scans a sample – not unlike what happens inside a cathode-ray tube. In 1940, Zworykin's team achieved the first magnification greater than 100,000x – a huge improvement in the technology.

In addition to his work in television and electron microscopy, Zworykin developed infrared 'night vision', missile guidance systems and security systems that used 'electric eyes'. He received a total of 120 US patents.

Above: Zworykin next to an early scanning electron microscope, around 1945. Zworykin did not invent the electron microscope, but led a team that made important improvements in the device, which has revolutionized biology, medicine and materials science.



Juan de la Cierva

(21 September 1895–9 December 1935)

A strange aircraft took to the air in 1923. It was the autogyro, an aeroplane with both a propeller and a rotor, invented by Spanish engineer Juan de la Cierva. Today, the autogyro is only flown by enthusiasts, having been superseded by the more manoeuvrable helicopter. The most important feature of helicopter design, however, the complicated mechanics at the hub of the rotor, was established in Cierva's autogyros.

Juan de la Cierva was born to a wealthy family in Mercia, Spain. As a boy, he was inspired by the early pioneers of flight, and he became determined to be an aviator himself. In 1911, he went to study civil engineering in Madrid. That year, he and two friends experimented with gliders, and formed an aviation company. In 1912, Cierva built the first aeroplane in Spain, but during the following few years two of his aeroplanes crashed after stalling at low speed. As a result, he became determined to build an



Pitcairn PCA-2 autogyro,
built in the U.S. under
Cierva license, 1961.





Helicopters

The autogyro, invented by Juan de la Cierva and later developed by Russian engineer Igor Bensen (1917–2000), was effective, safe, and moved through the air almost as fast as some aeroplanes did. Autogyros found several uses during the Second World War, including reconnaissance and even the bombing of submarines. But autogyros could not hover, or perform truly vertical landings and take-offs so eventually helicopters gained the edge once they became practical.

It was Russian-American aviation pioneer Igor Sikorsky (1889–1972) who established the blueprint for the modern helicopter. Sikorsky built his first helicopter in 1909 but, as with other inventors' attempts at the time, it did not work. After working on fixed-wing aircraft during the 1910s and '20s, Sikorsky produced one of the world's first successful helicopters, the VS-300, in 1939. He went on to design the first mass-produced helicopter, the Sikorsky R-4, in 1942. The layout of most helicopters has changed little since then.

Above: Russian-American helicopter pioneer Igor Sikorsky, flying his VS-300 helicopter in 1940. The VS-300 was the first helicopter to have a tail rotor; until then, helicopters had two counter-rotating main rotors to keep them stable in flight. Both designs are still common today.

aeroplane that could not stall. He came up with the autogyro: an aeroplane with a propeller at the front and rotating wings – rotor blades – at the top. The rotor blades would always be moving fast relative to the air, and producing lift, even when the autogyro was moving slowly.

Other inventors had experimented with rotors as early as 1907, but with little success. Cierva decided to leave his rotors unpowered, so that they would windmill or 'autorotate' as the autogyro moved through the air. This approach had an added benefit: if the engine cut out, the

autogyro would not crash to the ground. Instead, it would fall slowly, like a spinning sycamore seed case. In 1920, Cierva patented his idea, and tested small models of his autogyro concept. The models worked well, but when he scaled up his design, he found it had a tendency to flip over. He soon realized why. As it turns, each rotor blade spends half the time moving forwards – into the oncoming air – and half the time moving backwards. This means that the advancing blade is moving through the air faster than the receding blade and so the lift force is greater on one side than the other.

Successful prototype

Cierva looked back at his earlier models, and realized that the smaller rotor blades were flexible. As those rotors turned, the blades twisted slightly, automatically adjusting to the changing airspeed during each rotation, and producing constant lift. Cierva set about mimicking this phenomenon in his larger, metal blades. To do this, he incorporated a 'flapping hinge' where each rotor blade met the rotor hub. In January 1923, Cierva's first successful prototype, the C4, flew 180 metres (200 yards) at an airfield near Madrid. This was the first stable flight of a rotating-wing aircraft in history, and was quickly followed by many longer, more sustained flights. In 1925, Cierva demonstrated autogyro C6 in England and, with the support of an investor, formed the Cierva Autogiro Company. Three years



Above: A Cierva autogyro taking off from the South Grounds of the White House in Washington, DC, in 1931. The aircraft has fixed wings, like an aeroplane, but most of the lift force is provided by the rotor blades. In 1933, Cierva dispensed with the fixed wings altogether.

later, Cierva flew his C8 autogyro from England to France. The C8 featured a 'fully articulated rotor', with blades that could flex backwards to absorb the drag force (air resistance), which had previously caused some blades to snap.

More improvements followed, including a system to drive the rotor, just at take-off, so that the autogyro could rise vertically. The most obvious change came in 1933 when Cierva built autogyros with no wings and no tail. Up to this point, autogyros were controlled in the same way as fixed-wing aircraft: using moveable flaps on the wings and tail. This meant that pilots all but lost control at low speeds, so Cierva decided to find a way to control his autogyros by tilting the rotor. To do this, he had to design a complicated system of hinges and control levers around his rotor hub, and what he achieved formed the basis of all future helicopter rotors. Ironically, after devoting his career to avoiding the problems of stalling, Cierva was killed at Croydon airport, a passenger aboard a conventional fixed-wing aeroplane that stalled and crashed into a building just after take-off.



Above: A modern, fully articulated rotor. Each blade is able to move independently of the others, and can tilt to increase or decrease the lift force. Cierva developed the fully articulated rotor so that he could control his autogyros without fixed wings.



Above: A Focke-Wulf Fw-61, the first fully controllable helicopter, in 1937. German engineer Heinrich Focke (1890–1979) designed this after working on Cierva autogyros. The pilot is German aviator Hanna Reitsch (1912–1979), who set many records, including being the first woman to fly helicopters.



Wernher von Braun

(23 March 1912–16 June 1977)

German-American rocket engineer Wernher von Braun designed the first rocket-powered long-range ballistic missiles – but his real achievement was in spaceflight. His determination in following his boyhood dream of sending people to the Moon, together with his excellent technical and leadership skills, made him the ultimate spaceflight pioneer of the 20th century.

Wernher von Braun was born a baron, to an aristocratic family in the town of Wirsitz, in the then German Empire (now Wyrzysk in Poland). After the First World War, his family moved to Berlin, Germany. Young Wernher became interested in space when his mother, a serious amateur astronomer, gave him a telescope – and he was mesmerized by stories of journeys into outer space. von Braun studied mechanical engineering at the Charlottenburg Institute of Technology, in Berlin. While there, he joined the Verein für Raumschiffahrt (VfR) – the Society for

All images on spread © NASA

Dr. von Braun became
Director of the NASA
Marshall Space Flight
Center on 1 May, 1964.





The launch of the Apollo 11 mission, 16 July 1969, carried into space by a huge Saturn V rocket from Cape Kennedy, USA. This was the realization of a childhood ambition for von Braun, who led the project to design and build the Saturn V.



Above: Wernher von Braun, in 1954, holding a model of a proposed rocket that would lift people into space. During the 1950s, von Braun was a celebrity in the USA, nurturing dreams of space travel among the postwar American people.

Spaceship Travel – and became involved in building and firing early liquid-fuel rockets.

The Aggregate programme

von Braun joined the German army's Ordnance Division in October 1932, developing and testing rockets at an artillery range in Kummersdorf, near Berlin. He became technical head of the 'Aggregate' programme, whose aim was to design rockets for use as long-range ballistic missiles. In 1935, von Braun's team moved to Peenemünde, on the Baltic Coast, where the programme continued until the end of the Second World War. Each rocket in the proposed Aggregate series was bigger and more ambitious than the last. For example, the A9/10, had it been launched, would have been a 100-tonne, two-stage rocket aimed at New York, United States; the A12 would have been a true orbital launch vehicle, able to place satellites into orbit.

The only Aggregate rocket to see service was the A-4, better known as the V-2. Designed by



Above: Russian space visionary Konstantin Tsiolkovsky, whose 1903 book *The Exploration of Cosmic Space by Means of Reaction Devices* was the first serious scientific treatise on using rockets to reach space.



Above: Officials of the US Army Ballistic Missile Agency at Redstone Arsenal in Huntsville, Alabama. von Braun is second from right; in the foreground is Romanian rocket pioneer Hermann Oberth.

Early spaceflight pioneers

It was when he read *Die Rakete zu den Planetenräumen* (The Rocket into Interplanetary Space) that Wernher von Braun set about learning the mathematics, physics and engineering necessary to make space travel a reality. The book was written by German rocket pioneer Hermann Oberth (1894–1989), in 1923.

Oberth was one of three visionaries who independently worked out how multi-staged rockets could be used to lift into space. The other two were Russian mathematics teacher Konstantin Tsiolkovsky (1857–1935) and American physicist Robert Goddard (1882–1945). In 1926, Goddard became the first person to build and fly a liquid-fuel rocket, in his aunt's farm in Massachusetts. In his day, Goddard was ridiculed in the press. Nevertheless, Wernher von Braun, although himself an innovator, based much of his early work on Goddard's research.



“von Braun became something of a celebrity, promoting the idea of space travel”

von Braun's team, this was the world's first medium-range ballistic missile – and the first reliable liquid-fuel rocket. By the end of the war, more than 3,000 had been launched; these terrible weapons, built by prisoners-of-war, rained destruction upon England, Belgium and France from 1944 onwards. von Braun's involvement in the weapon's development and his membership of the Nazi party remain controversial, but he was always preoccupied with his real goal of sending rockets into space. When the war ended, the US Army took von Braun and his team of workers to the United States. In 1950, von Braun settled in Huntsville, Alabama, where he headed the US Army rocket team. At that time, the Cold War was intensifying, and the United States was worried that the Soviet Union might dominate the new territory of space. Throughout the 1950s, von Braun became something of a celebrity, promoting the idea of space travel in books, magazines, on television and in films – inspiring the American people with his dreams of space stations and journeys to the Moon and Mars.

The Space Age officially began on 4 October 1957, when the Soviet Union launched the first

satellite, Sputnik 1, into orbit. The news prompted the United States Government to form NASA (the National Aeronautics and Space Administration). In 1958, a Redstone rocket, designed by von Braun, put America's first satellite into orbit. Two years later, NASA opened its Marshall Spaceflight Center, in Huntsville, and von Braun became its director. The Soviet Union got the upper hand again in 1961, when it launched a human into space for the first time; the United States retaliated by launching Alan Shepherd into space less than a month later, again with a von Braun Redstone rocket.

In May 1961, to von Braun's delight, United States president John F Kennedy (1917–1963) announced the country's intention of “landing a man on the Moon and returning him back safely to the Earth”. The United States succeeded – and the astronauts of the ‘Apollo’ programme travelled to the Moon in modules launched into space atop huge Saturn V rockets, designed by von Braun's team at the Marshall Space Center. von Braun had finally achieved his goal of interplanetary travel and NASA call him “without doubt, the greatest rocket engineer in history.”



Above: An A-4 rocket on a test launch at Peenemünde, 1943. The A-4 became the V-2 when used in World War II. Payload: 1 tonne; maximum altitude: 95 kilometres (50 miles); maximum speed: 5,800 kilometres per hour (3,600 miles per hour); range: 320 kilometres (199 miles).



Alan Turing

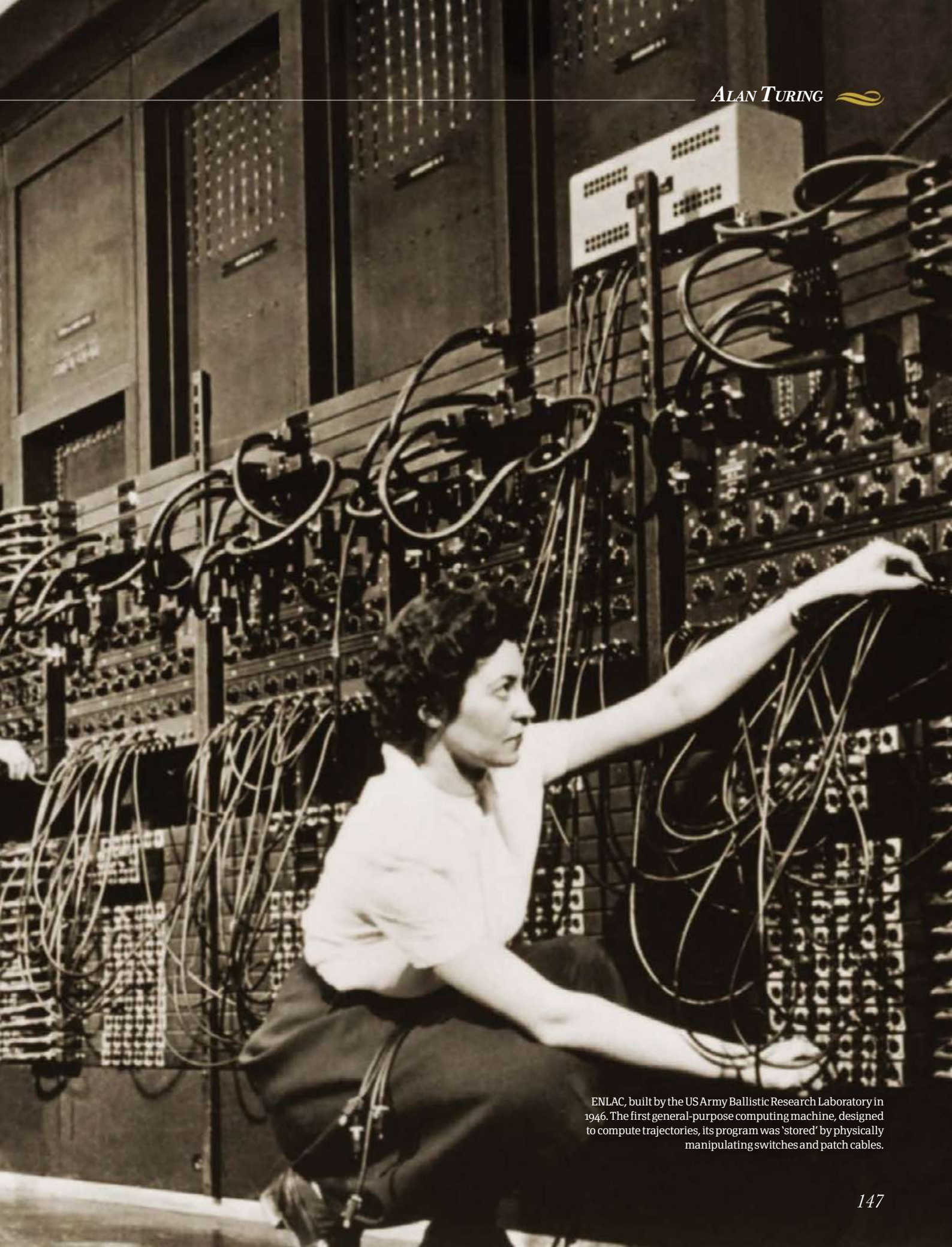
(23 June 1912–7 June 1954)

The first electronic digital computers appeared in the 1940s. They were not simply the result of advances in electronics. Their development relied on a theory of computation formulated by English mathematician Alan Turing, who was also an important wartime code-breaker and a pioneer of machine intelligence.

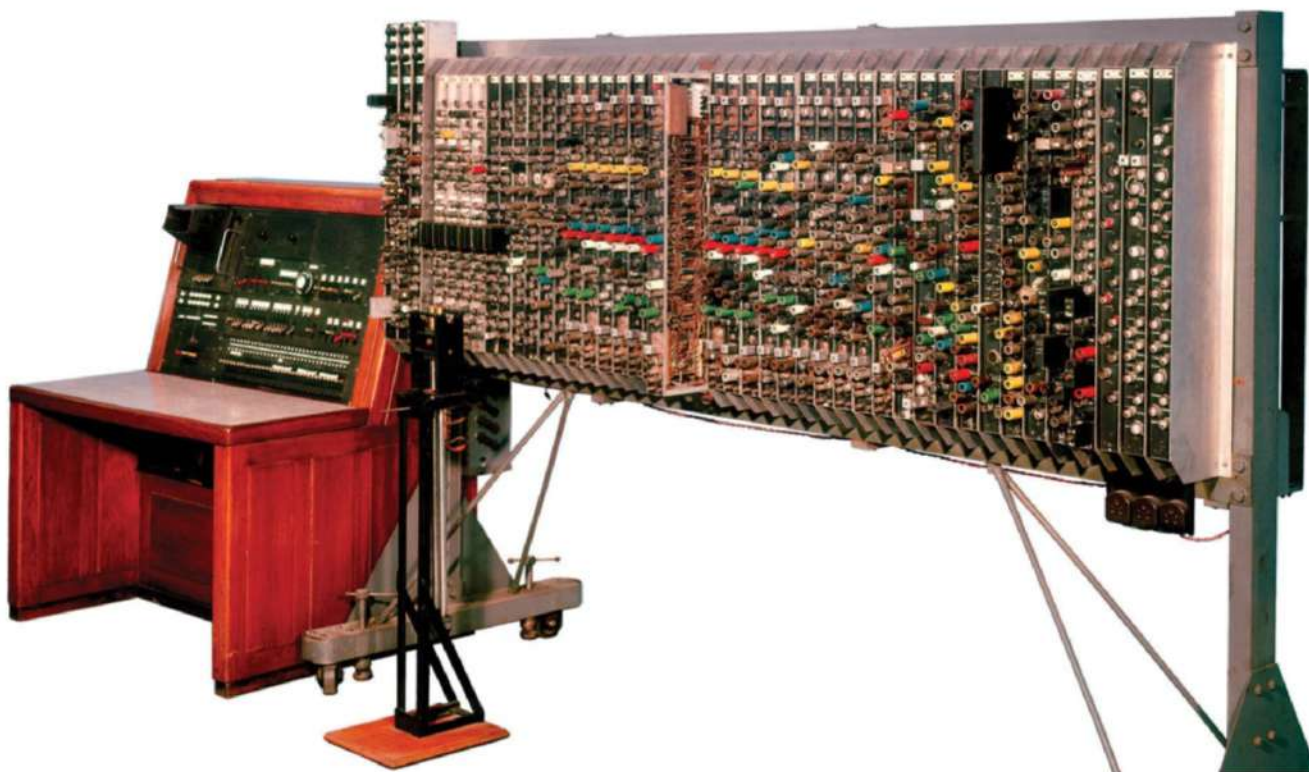
Alan Turing was born in London to an upper-middle-class family, and his genius was evident from an early age. He taught himself to read in a matter of weeks and while in his teens at the auspicious Sherborne public school in Dorset he developed a fascination for science and mathematics. In 1931, he went to King's College, Cambridge, to study mathematics.

While he was at university, Turing became interested in logic. This was a hot topic in mathematics at the time: mathematicians were attempting to define their subject completely in terms of logic – to iron out inconsistencies and to





ENIAC, built by the US Army Ballistic Research Laboratory in 1946. The first general-purpose computing machine, designed to compute trajectories, its program was 'stored' by physically manipulating switches and patch cables.



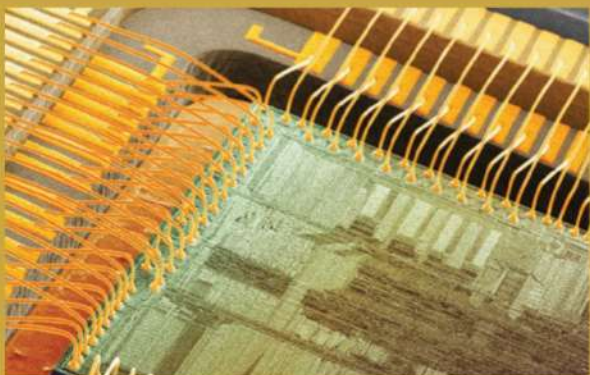
Above: Pilot ACE, 1950. Towards the end of World War II, Turing told his colleagues he was “building a brain”: the Automatic Computing Engine (ACE). After the war, Turing presented his design to the National Physical Laboratory. Pilot ACE was the prototype based on Turing’s design.

show that mathematics is ‘logically complete’. In 1931, German mathematician Kurt Gödel (1906–1978) had published two theorems that showed this was impossible. He proved that even simple mathematical statements rely on assumptions and intuition that cannot be defined in terms of logic.

Inspired by Gödel’s theorems, Turing wrote a landmark paper on the logic of mathematics in 1936. In this paper, Turing imagined an ‘automatic machine’ that could read and write symbols on a tape, and carry out tasks based on a simple set of instructions. Turing proved that any problem that is ‘computable’ can be solved by such a machine

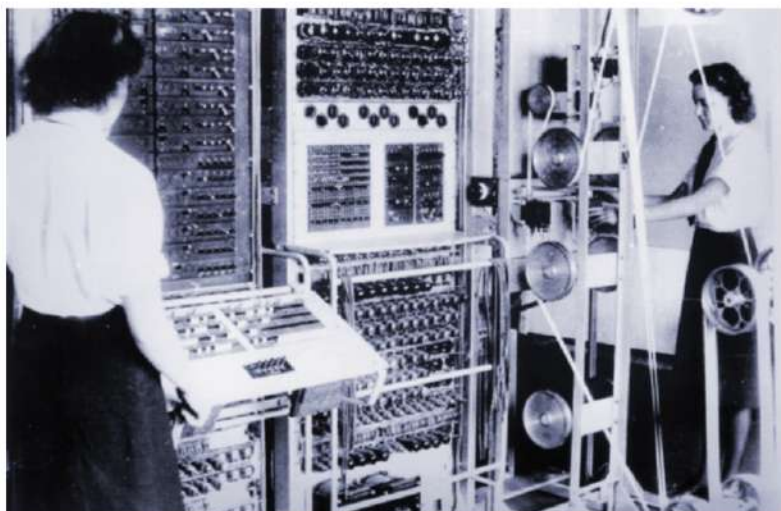
– a ‘universal’ computer – if given the correct set of instructions. This was another way of expressing Gödel’s theorems, since it also proved there were some mathematical statements that the machine could not compute. It was significant for another reason: Turing’s hypothetical device became known as the ‘Universal Turing Machine’ and was to be the blueprint for digital computers.

During the Second World War, Turing worked for the UK government helping to decode the German military forces’ encrypted communications, at a Buckinghamshire mansion called Bletchley Park. The Germans used two devices, the Enigma machine and the Lorenz



The central processing unit

A general-purpose computer is defined by the presence of a CPU (Central Processing Unit) to carry out instructions, memory to hold the instructions and some form of input and output. This basic architecture is called the von Neumann architecture, after Hungarian-American mathematician John von Neumann (1903–1957). In 1945, he presented a paper to the US Army proposing a general-purpose computing machine, with the ability to store programs. His proposal was based on the idea of the Universal Turing Machine developed by Turing. The computer was the EDVAC (Electronic Discrete Variable Automatic Computer), one of the earliest general-purpose computers, which ran its first programs in 1951. In modern computers, the CPU is contained on a chip of semiconductor called a microprocessor.



Above: A Colossus code-breaking computer at Bletchley Park, UK, 1943. Designed by English electronic engineer Tommy Flowers (1905–1998), the Colossus was the first fully electronic, stored-program computer – but it was not a truly general-purpose computer.



Above: John von Neumann, photographed in the 1940s.

In his now-classic 'First Draft of a Report on the EDVAC', von Neumann established the basic 'architecture' of modern computers – although he was greatly inspired by ENIAC, which he had used in the development of the hydrogen bomb.

Cipher machine, to produce extremely well-encrypted communications. Although possible to find 'keys' to crack the encryption, this was a laborious process. In the early 1930s, Polish code-breakers had built a machine that sped up the process. But in 1939, the Germans improved their machines, making the codes even harder to crack. Turing in turn designed a more efficient and faster machine, which he called 'The Bombe'. By the end of the war, 211 Bombes were operational, requiring 2,000 staff to run them. Turing's invention greatly helped the war effort, and probably shortened the war by a year or more.

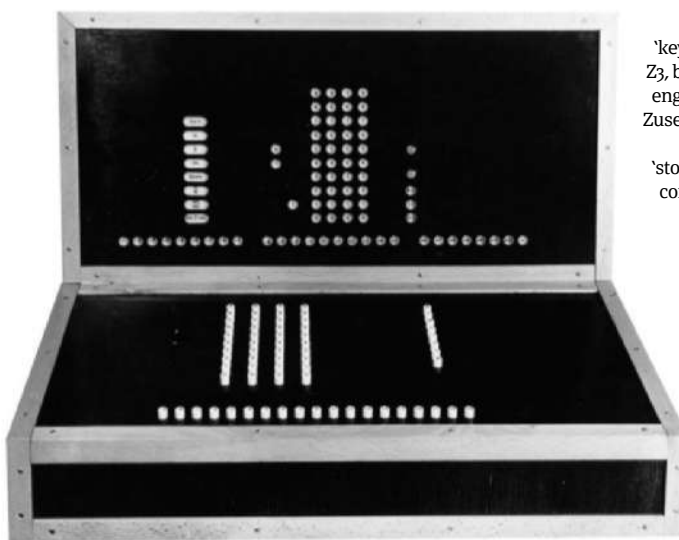
conversations via a keyboard and monitor – one with a human being and one with a computer. If the judge was not certain which was which, the computer would be deemed intelligent. No computer has yet passed the test.

In 1945, Turing was awarded the OBE (Order of the British Empire) for his work at Bletchley Park, but in 1952 he was convicted for homosexuality, then illegal in the UK (the UK government issued a posthumous apology to Turing in 2009). Two years after his conviction, he was found dead in his bed from cyanide poisoning; an inquest concluded that it was suicide.

Post-war developments

After the war, he wrote a proposal to the National Physical Laboratory in London for an 'automatic computing engine', based on his Universal Turing Machine. While his proposal was accepted, it was thought too ambitious, and a smaller version – the Pilot ACE – was built instead. It ran its first program in 1950. Other researchers were working on Turing Machines, too. The world's first stored-program, general-purpose computer was the Small Scale Experimental Machine, built by a team at the Victoria University of Manchester, also in England. It ran its first program in 1948.

Turing was well aware of the possibility that machines might one day 'think'. In an article in 1950, he suggested a test for artificial intelligence: a person (the judge) would have two



Left: The 'keyboard' of the Z3, built in 1941 by engineer Konrad Zuse (1910–1995). It was the first 'stored-program' computer to use binary to represent numbers and instructions.



Gertrude Elion

(23 January 1918–21 February 1999)

The inventions of American biochemist Gertrude Elion are far too small to see. They are works of engineering, but at the molecular level: Elion was a pioneer of chemotherapy. The medicines she developed have brought hope to millions of people with bacterial and viral infections and cancer.

Gertrude Elion was born in New York, USA. Her mother was from Russia, her father from Lithuania. As a child, 'Trudy' had an insatiable desire to read and learn, and she took an interest in all subjects. It was the fact that her grandfather had died of leukaemia that fostered her interest in science. At the age of 15, she began studying chemistry at Hunter College, New York, in the hope that she might one day develop medicines to cure or prevent the disease that had claimed her grandfather.

The campus at Hunter College was for women only, so Elion was used to women studying science. However, in the world outside college,



GERTRUDE ELION 

Gertrude Elion and George Hitchings, shortly after winning the Nobel Prize for Medicine in 1988. In 1991 Elion became the first woman to be inducted into the US National Inventors Hall of Fame. She worked closely with Hitchings for much of her career.

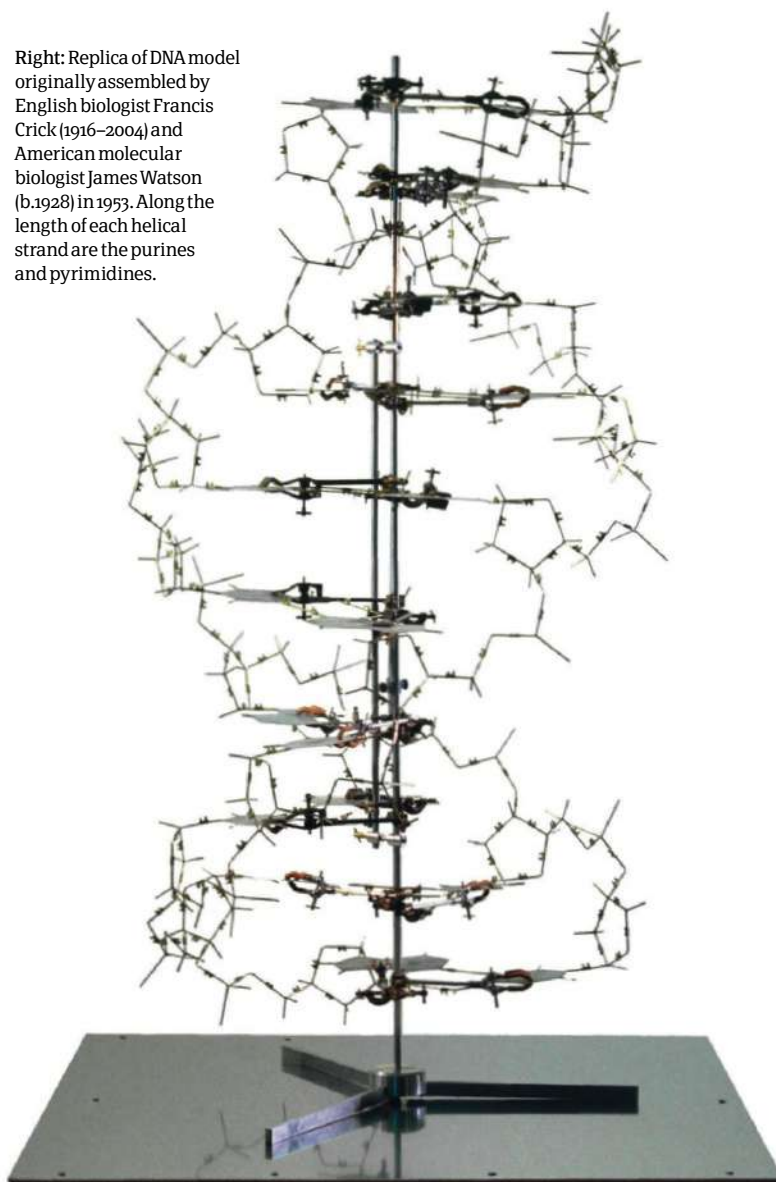


men still dominated, and despite her outstanding academic record, Elion found it impossible to get funding to take on a PhD. By doing several poorly paid jobs, she managed to save up enough money to enrol at night school, and she received a masters degree in 1941, but never received a PhD. That year, many men were out of the country fighting in the Second World War, so some laboratories were employing women. In 1944, after several years of working in unchallenging jobs in the chemical industry, Elion began work as a senior research chemist in the New York laboratory of the pharmaceuticals company Burroughs Wellcome. There she worked as an assistant to American doctor and chemist George Hitchings (1905–1998), who encouraged her to learn as much as possible and to follow her own lines of enquiry.

Biochemistry

Although Elion had studied chemistry, her quest to produce medicines had led her to biochemistry (the chemistry of living things), pharmacology (the study of how drugs work) and virology (the study of viruses). By the 1940s, biochemists had discovered that a chemical called DNA (deoxyribonucleic acid) present in the cell nucleus was involved in cell replication. They had worked

Right: Replica of DNA model originally assembled by English biologist Francis Crick (1916–2004) and American molecular biologist James Watson (b.1928) in 1953. Along the length of each helical strand are the purines and pyrimidines.



“Biochemists discovered that DNA was involved in cell replication”

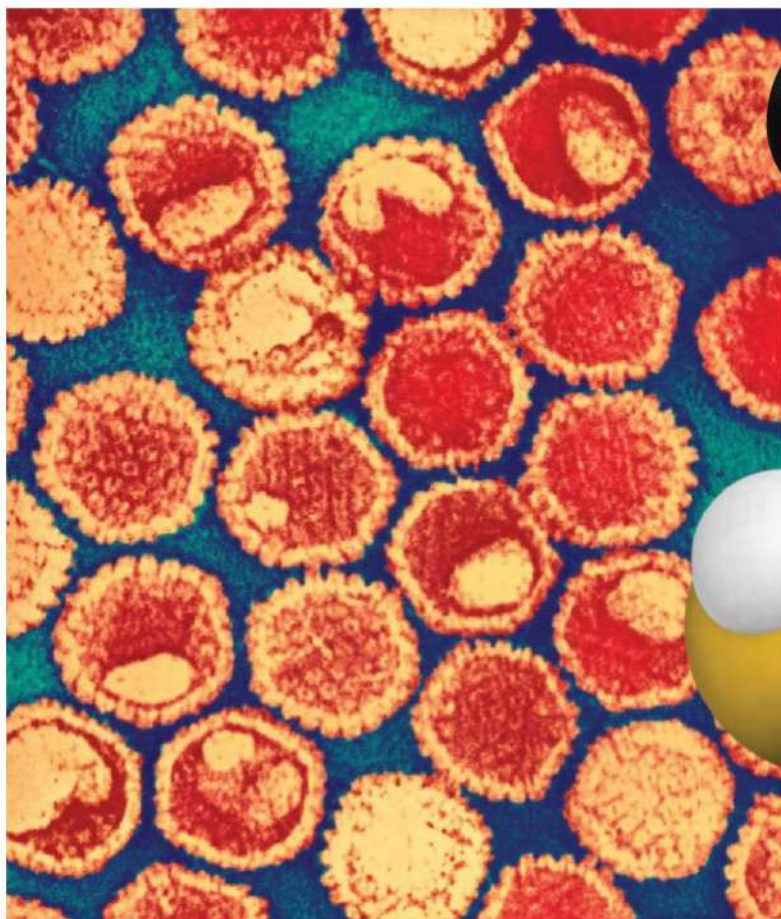
Transplant surgery

In 1958, American doctor William Dameshek (1900–1969) suggested that Gertrude Elion's anti-leukaemia drug 6-MP might be effective at suppressing the immune system. If true, the drug might prevent the body's rejection of organs after transplant surgery. Dameshek's rationale was that the white blood cells responsible for the immune response were similar to the white blood cells involved in leukaemia.

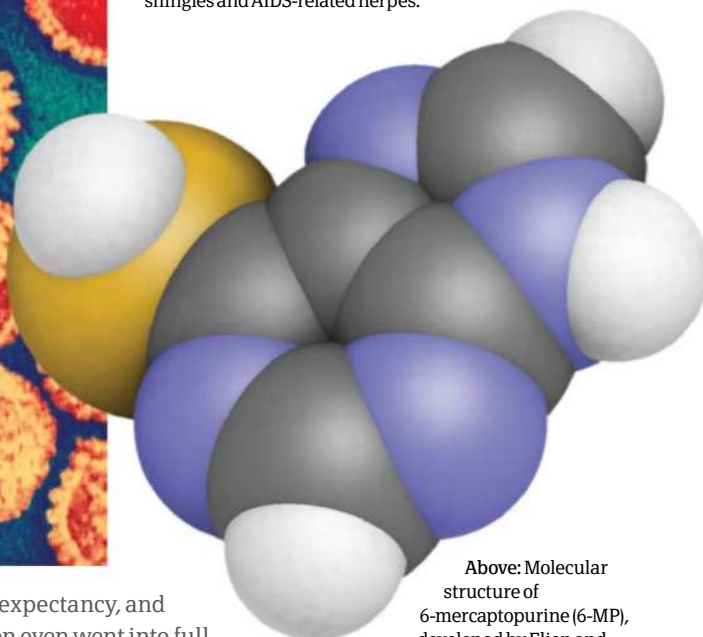
In 1960, English transplant pioneer Roy Calne (b.1930) tested 6-MP in dog

kidney transplants, and found that it was fairly effective. Gertrude Elion suggested that a related compound, azathioprine, might be more effective, and Calne conducted promising trials with the new drug in 1961. The first successful kidney transplant between unrelated humans was performed soon after, using azathioprine. In combination with corticosteroids, this drug became the mainstay of transplant surgery, until it was replaced by a more powerful drug, cyclosporine, in 1978.





Above: Today there are dozens of anti-viral drugs available, including this one, Valtrex®. The active ingredient in this drug is a derivative of acyclovir, developed by Elion. Valtrex® is used to treat all kinds of herpes infections, including genital herpes, shingles and AIDS-related herpes.



Above: Molecular structure of 6-mercaptopurine (6-MP), developed by Elion and Hutchings in 1951. 6-MP has a very similar shape to purine molecules found along the length of DNA, and it interrupts their formation, inhibiting the rampant reproduction of DNA characteristic of cancers.

out the constituent parts of DNA, but its double helix structure would not be worked out until 1953. The most important constituents are small molecules called purines and pyrimidines, which join together in pairs along the length of the much larger DNA molecule. Elion wondered whether altering these molecules might somehow confuse a virus or a bacterium or stop the uncontrolled reproduction of cancer cells. So she and Hitchings set about engineering new ones.

Elion and Hitchings made their first breakthrough in 1948. One of their purines, 2,6-diaminopurine, was found to restrict the reproduction of bacteria, and to slow the growth of tumours in mice. Over the next few years, Elion tested more than 100 other engineered purines. In 1951, trials in rats suggested that one of them, 6-mercaptopurine (6-MP), could fight leukaemia. At the time, there was little hope for patients with leukaemia, most of whom were children and most of whom died within a few months of diagnosis. When 6-MP was tested in humans, it was found to

increase life expectancy, and some children even went into full remission. The drug is still used today in anti-cancer chemotherapy.

With increasing knowledge of biochemical reactions at the heart of cell biology, Elion went on to synthesize several medicines effective against a range of bacterial diseases, including malaria, meningitis and septicaemia. In 1958, she produced the first medicine that could suppress the immune system, making organ transplants safer (see box). In 1981, after more than a decade's work, she created the first anti-viral drug, acyclovir, which is the active substance in anti-herpes medicine such as Zovirax® and Valtrex®. Gertrude Elion received many awards for her groundbreaking work in chemotherapy, including, in 1988, the Nobel Prize in Physiology or Medicine. She shared the prize with George Hitchings and Scottish pharmacologist James Black (b.1924), for 'discoveries of important principles for drug treatment'.

Top Left: False-colour electron micrograph of herpes simplex viruses. Each virus comprises DNA in a protein 'cage' (the capsid), surrounded by a fatty membrane (the envelope). A virus uses resources inside a host cell to reproduce; Elion produced the first effective anti-viral drugs, which inhibit this process.



Tim Berners-Lee

(born 8 June 1955)

In modern life, it seems increasingly hard for an individual to invent something that truly changes the world. However, one person who did just that is English physicist and computer scientist Tim Berners-Lee. In 1990, he launched the World Wide Web.

Timothy Berners-Lee was born in London. His parents were both computer scientists. As a boy, Tim became interested in electronics after building circuits to control his model train set. He studied physics at Oxford University; while he was there, he built his first computer. After graduating in 1976, he worked as a computer systems engineer at various companies.

In 1980, Berners-Lee spent six months at the European Organization for Nuclear Research, a particle physics facility in the outskirts of Geneva, on the border between France and Switzerland. It is better known by the acronym CERN, which derives from the facility's original name, Conseil Européen pour la Recherche Nucléaire. While at



Tim Berners-Lee
at the Home
Office, London.



Above: During the 1960s most large businesses and universities had a centralized 'mainframe' computer like this. Computer networking, upon which the Web depends, originated in efforts to establish time-shared access to these machines via terminals distributed through the organization.



Above: A 1994 screenshot of the first web browser, World Wide Web. Berners-Lee wrote the software exclusively for NEXT computers, like the one he used at CERN. The software could read and edit pages written in html, open linked pages and download any linked computer files.

CERN, Berners-Lee devised a computer system, for his own personal use, to store and retrieve information. Named ENQUIRE, this was a forerunner of the Web. It was based upon hyperlinks, cross-references in one document that enable a computer to call up another, related document.

In 1984, Berners-Lee was back at CERN, on a computing fellowship programme. He became frustrated by the lack of compatibility between different computer systems, and between documents written using different software applications. In a memo he sent to his manager in 1989, Berners-Lee set out his vision of a 'universal linked information system' with which to organize the huge amounts of information produced at CERN. He proposed that a 'web of links' would be more useful than the 'fixed, hierarchical system' that existed. Documents available on computers within CERN's network would contain hyperlinks to other documents, including those on different computers. In 1990, Berners-Lee's manager encouraged him to spend some time – as a side project – on developing his idea.

During the autumn of 1990, Berners-Lee, along with his colleague, Belgian computer scientist Robert Cailliau (b.1947), created all the now-familiar fundamental components of the World Wide Web. The universal language he invented for writing linked documents (web pages) is 'html' – hypertext markup language. The software that





“Within a few short years, most people in the world had been affected directly by its existence”

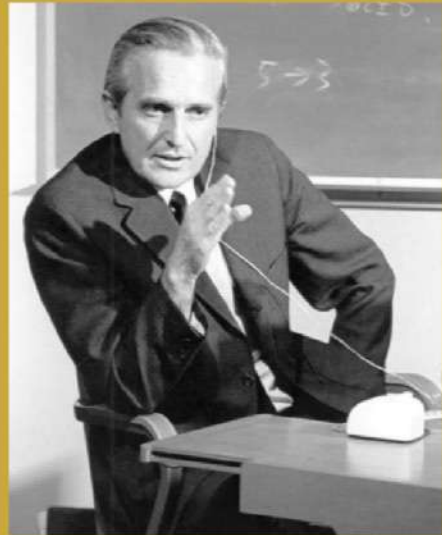
responds to 'requests' from hyperlinks is called a 'web server', a term that also refers to the hardware that hosts the web pages. And the language, or protocol, computers use to communicate the hyperlink requests is 'http' – hypertext transfer protocol. Berners-Lee had to write the first web browser, the application used to view the documents hosted on web servers. He called his browser 'WorldWideWeb'. Berners-Lee also wrote the first web pages, which he published on his server in December 1990. It was on 25th of that month that Berners-Lee first 'surf' from one web page to another, via http, by clicking a hyperlink in his browser.

Going global

The following year, Berners-Lee made available his software to people outside CERN, and the idea quickly caught on. By 1994, the Web had grown so much that each 'resource' – a document or image, for example – needed a unique 'address' on the Internet. In consultation with the Web community, Berners-Lee created the format for web addresses, called the 'uniform resource locator' (URL). After 1994, the Web spread rapidly beyond academic and military circles. Within a few short years, most people in the world had

Top: plaque at CERN commemorating the invention of the Web.

Left: The actual 'NeXTcube' computer Berners-Lee used to host the first web page, and to write the software necessary to implement his idea. The computer was connected to the local network at CERN. A sticker on the processing unit reads: 'This machine is a server: DO NOT POWER DOWN!'



Doug Engelbart (1925–2013)

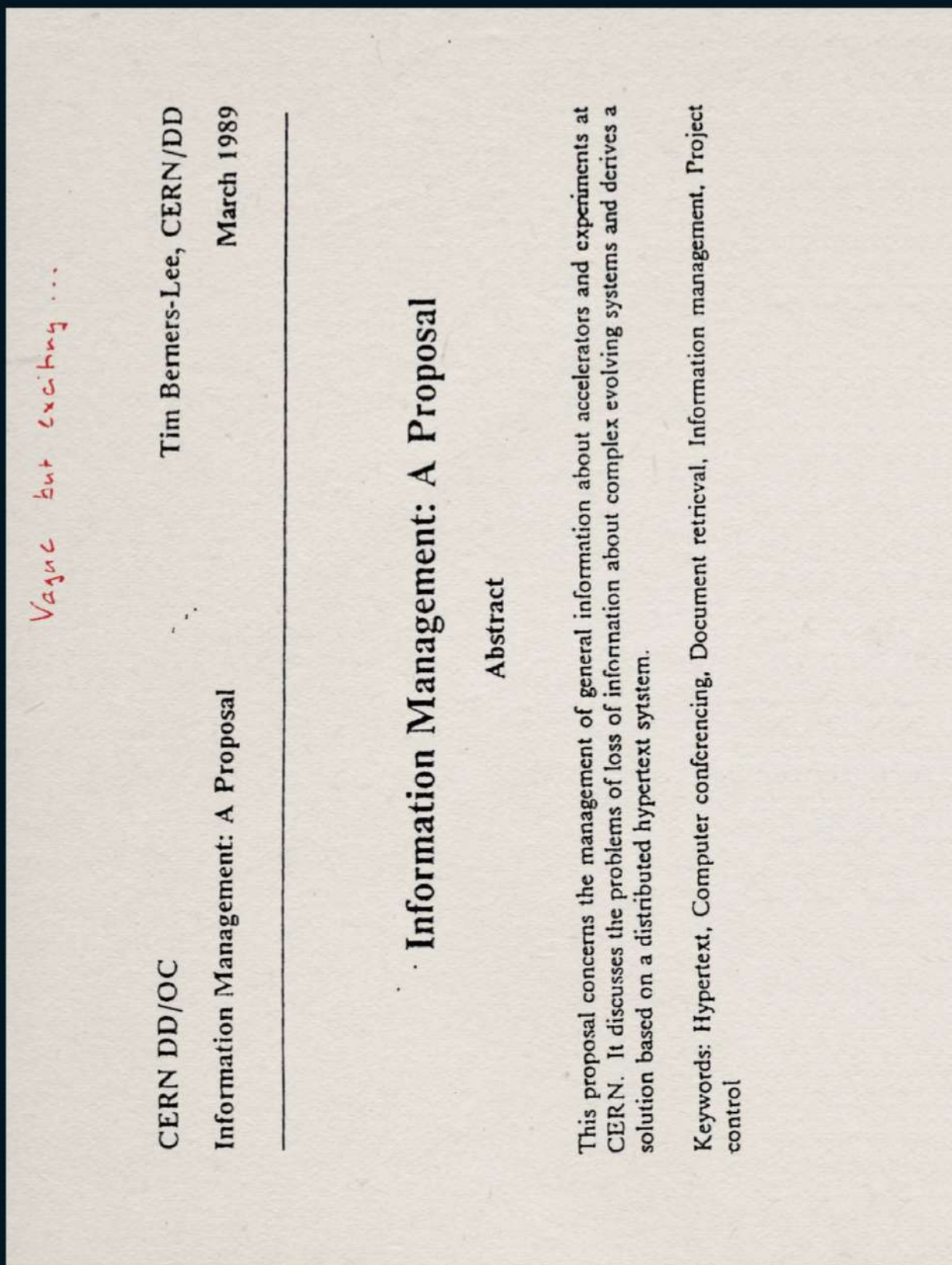
Two very important technologies underpinned Tim Berners-Lee's invention of the World Wide Web: hyperlinks and the computer mouse. American computer scientist Douglas Engelbart invented the mouse in 1967, and he was also heavily involved in the development of hyperlinks.

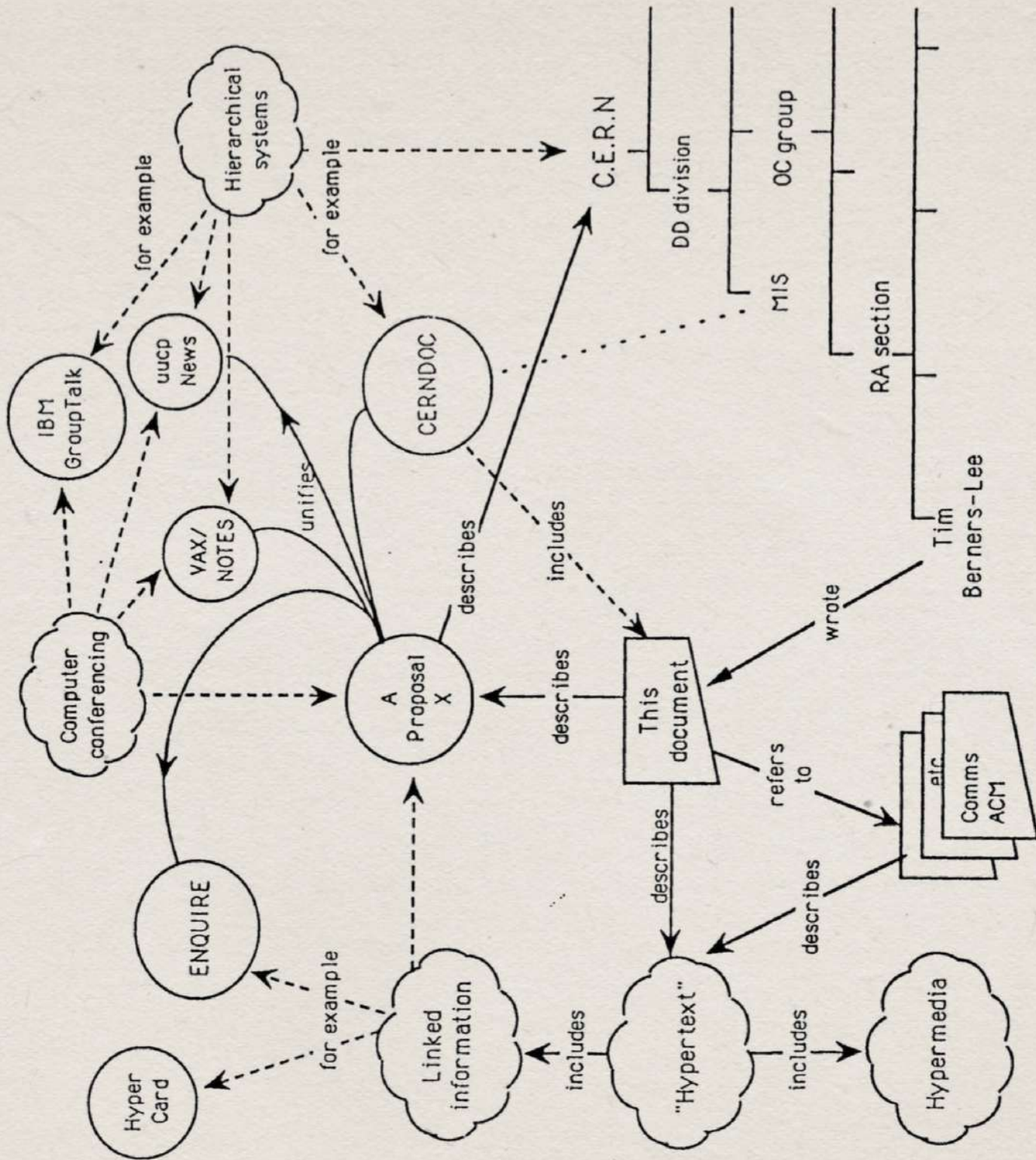
In the 1960s, Engelbart headed a team at the Augmentation Research Center, at the Stanford Research Institute, California. Engelbart's team devised an online 'collaboration system' called NLS (on-Line System). This included the first use of hyperlinks and the mouse, which Engelbart invented in 1967. In 1968, Engelbart demonstrated NLS to a large audience of computer scientists. In addition to hyperlinks and the mouse, the 90-minute session, normally referred to as 'The Mother of All Demos', introduced such ideas as e-mail, video-conferencing and real-time collaboration between computer users far apart.

been affected directly by its existence, and millions were already regularly 'surfing' from document to document online.

Tim Berners-Lee has received a huge number of accolades for his invention, which he gave free to the world without patents or rights. In 1994, he founded the World Wide Web Consortium, which helps keep the Web working smoothly and aims to foster its future growth. He also campaigns to keep the Internet 'neutral' – free of restrictions on content and what kinds of computers may be connected.

Left: The first page of the historic proposal for 'Information Management' at CERN, submitted by Berners-Lee in March 1989, to his boss Mike Sendall (1939–1999). The words "vague but exciting" were written by Sendall, who encouraged Berners-Lee to spend some time on his idea the following year.





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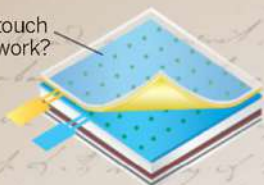
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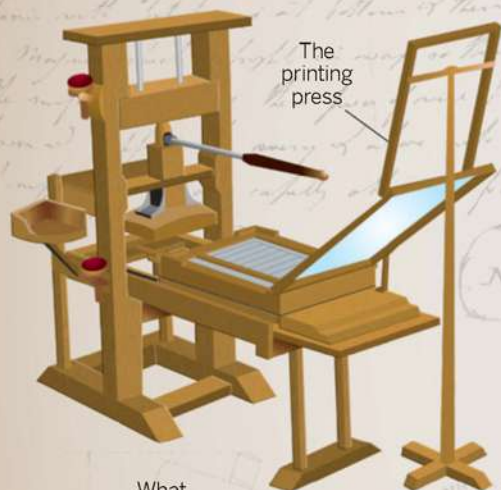
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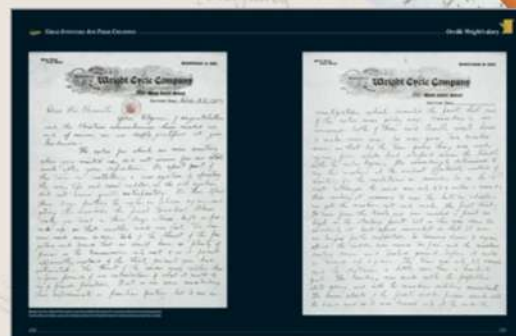


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